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CONTRIBUTIONS, ABSTRACTS, AND BIBLIOGRAPHY

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CHARTS

†In marine separate.

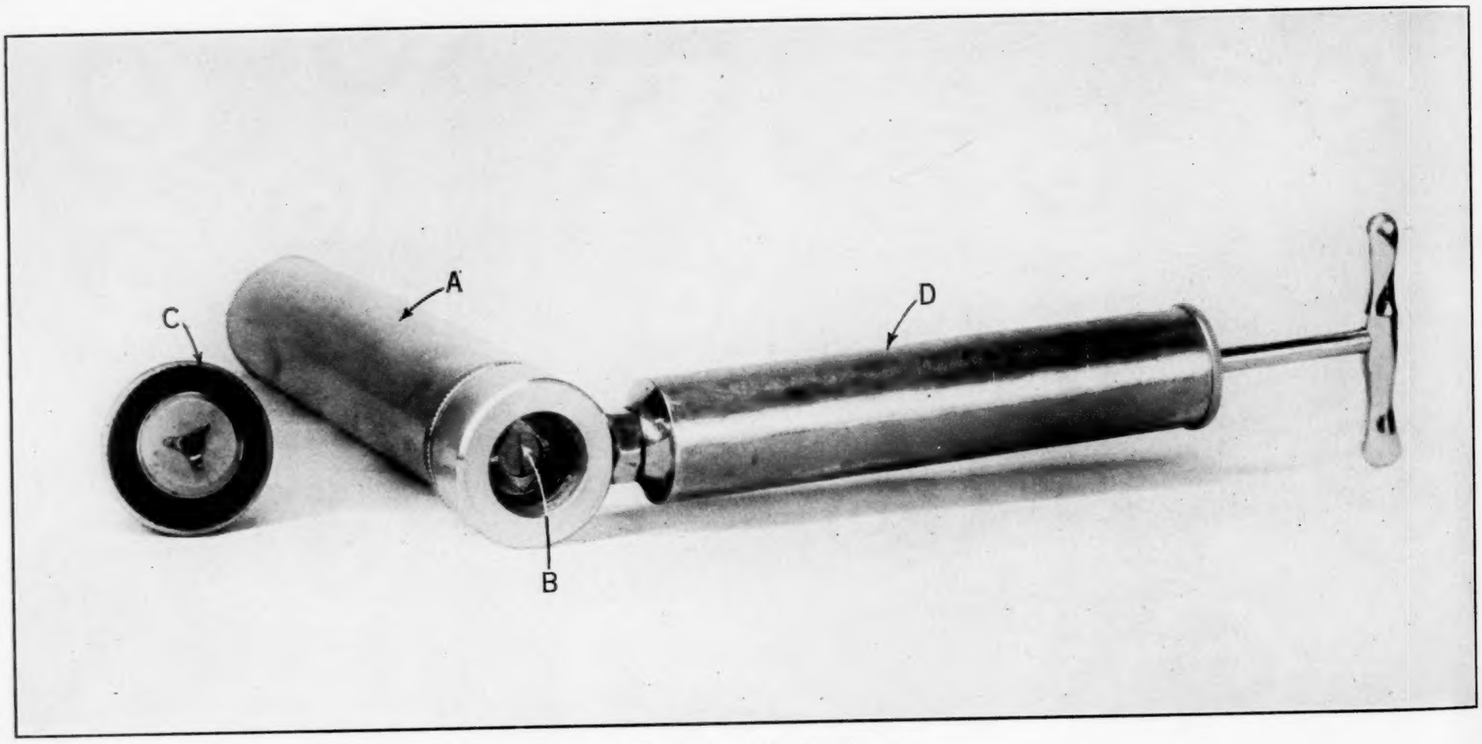

FIG. 1.—Owen's dust counter

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INVESTIGATION OF THE DUST CONTENT OF THE ATMOSPHERE

By Herbert H. Kimball and Irving F. Hand

[Weather Bureau, Washington, D. C., February 5, 1924]

SYNOPSIS

This paper summarizes observations with an Owen's dust counter furnished to the Weather Bureau by the Bureau of the Meteorological Section of the International Union of Geodesy and Geophysics, to promote international cooperation in a study of the dust content of the atmosphere. A similar instrument has been furnished to eleven other countries affiliated with the Union.

Most of the measurements by the Weather Bureau have been made at the American University, a thinly settled suburb to the northwest of the city of Washington. Some have been made at the central office of the Weather Bureau, and at the base and top of the Washington Monument, within the city. A few have been obtained in other cities, and interesting series have been obtained during airplane flights.

A summary of the results shows at the American University an average of about 850 particles per cubic centimeter in winter, and about 400 during the summer months. The extremes vary between about 4,000, on an unusually smoky day in January, 1923, and about 100 on unusually clear days throughout the year. A comparison of December, January, and February, 1922–23 with the same months in 1923–24 shows an excess of over 75 per cent in the number of dust particles in 1922–23, which is attributed to a general use of bituminous coal for heating purposes at that time on account of a shortage in the supply of anthracite.

During January, 1924, counts at the central office of the Weather Bureau gave more than double the number of particles found at the university, with a maximum of 6,046 particles per cubic centimeter. During February, probably on account of increased wind movement, the excess at the Weather Bureau was only 26 per cent.

A few measurements made in Chicago between September 24 and October 11, 1923, under average conditions, gave at the Federal Building a maximum of 7,180 particles per cubic centimeter, and at the University of Chicago a maximum of 4,800 particles.

The records obtained during airplane flights show a marked decrease in the dust content of the atmosphere above an altitude of 6,000 feet in August and 3,000 feet in October and November. Also a general decrease at all levels up to 7,000 feet after a rainstorm. There is also a slight excess at high levels on clear days, as compared with cloudy days due to the dust carried upward by convection currents.

A close relation is shown between the dust content of the atmosphere and the visibility both at the surface and from the altitude at which airplanes usually fly.

Object of the investigation.—At the meeting of the International Union of Geodesy and Geophysics that was held in Rome, Italy, in May, 1922, provision was made for an international study of the dust content of the atmosphere.

Several considerations make such a study worthy of international effort.

For example, visibility is an important factor in navigating both the sea and the air. Just what is the relation between visibility and atmospheric dustiness?

To what extent is the atmosphere of cities polluted by the incomplete combustion of fuel?

We know that after a violently explosive volcanic eruption the fine dust that is thrown to great heights sometimes floats in the atmosphere for several years before it finally falls to the ground. Just how widely is this dust distributed by the wind currents?

Will it be possible to detect the presence of dust that finds its way into our atmosphere from interplanetary space?

Apparatus.—As an aid to the solution of these problems, provision was made at Rome for the construction of 12 dust counters, of a kind designed by Dr. J. S. Owens of London, and for their distribution to metorological observatories in the different countries affiliated with the union. One of these counters was sent to the United States Weather Bureau, and has been in daily use since December, 1922.

The Owen's dust counter shown in Figure 1 (frontispiece), has three essential parts, as follows:

(1) A dampening chamber, A, which is simply a tube open at one end and lined with blotting paper which is thoroughly saturated with water.

(2) The other end of the tube is closed by a screw-threaded head, except for a narrow slot, B, 1 centimeter long; and above this slot is a bed for holding a microscope cover glass. When the end of the head is closed by the screwed plug, C, the three-claw spring presses upon the cover glass and holds it in place.

(3) A passageway leads from the space between the slot and the cover glass to an air pump, D, by means of which the air pressure above the slot may suddenly be greatly reduced.

This reduction in pressure accomplishes two things:

(*a*) It causes the air to pass at high velocity through the slot from the dampening chamber.

(*b*) The reduction in pressure as the air passes through the slot cools the already satuated air below its dewpoint and moisture is condensed upon the dust particles.

As a result of the above, the moisture-covered particles impinge upon the microscope cover glass at sufficient velocity to cause them to stick. If the cover glass is removed at once a line of moisture will be visible. This quickly evaporates, however, leaving an invisible line of dust particles.

The cover glass is next mounted on a microscope slide and examined. The first examination, for the purpose of locating the line of dust, is usually with a 16-mm. objective and an eyepiece magnifying 8 times, which gives a magnification of 125 diameters. To count the number of particles, a 1.8-mm. objective is used, with oil immersion, giving a magnification of 1,000 diameters. An eyepiece magnifying 12 times, with a 1.8 objective, giving a magnification of 1,500 diameters, is sometimes used.

With a magnification of 1,000 diameters dust particles 0.2 μ, or 0.0002 mm. in diameter may be seen.

Attention is invited to the difference in the results to be expected between dust determinations by this method

and by that followed by Aitken and others. Aitken[1] counted the number of water drops formed when the air was cooled far below its dewpoint. Particles much too small to be seen under the microscope, and even molecules of hygroscopic gases, would serve as nuclei for condensation. Therefore he found many more particles per cubic centimeter than can be detected by the method employed in this research. Particles less in diameter than the wave length of ultra-violet light (0.0002 mm.), can not be made visible under the microscope.

The present research is concerned more particularly with the surface dust layer,[2] in which we live, and which contains most of the pollution resulting from human habitation. These particles are generally of sufficient size to be seen by the aid of a microscope.

Monthly averages of dust content of the atmosphere.—Figure 2 shows graphically the maximum, minimum, and mean number of dust particles per cubic centimeter, derived from the early morning dust counts at the American University. At once the seasonal variation, especially in the maximum number of particles, is apparent. Evidently the University is not outside the area of city smoke, especially when the wind is light with an easterly component. During the month of June the observations were made at the central office of the Weather Bureau, and the increased number of dust particles found is shown in the monthly mean and extremes.

TABLE 1.—*Summary of atmospheric dust counts, American University, 8 a. m.*

GROUP A. DECEMBER TO MARCH, INCLUSIVE

Number of observations	N	Humidity		Wind		Visibility
	Per c. c.	R. H.	e	Dir.	Vel.	
		Per ct.	*mm.*		*m. p. h.*	*Miles*
5	102	47	2.85	NW	15	50
3	238	51	1.71	NW	17	50
2	156	66	4.66	NNW	6	30
3	350	46	1.46	NW	14	30
7	218	58	2.82	NW	10	17
4	469	51	3.77	SW	6	15
7	396	73	3.80	NW	9	10
5	735	73	6.12	SW	4	10
14	479	68	3.94		6	6
8	1,082	72	3.97		5	5
7	853	70	2.94		7	3
10	1,560	68	3.17		5	3
14	1,342	82	4.12		4	1
3	3,218	84	4.33		1	½

GROUP B. APRIL, MAY, JULY TO NOVEMBER, INCLUSIVE

Number of observations	Per c. c.	R. H.	e	Dir.	Vel.	Visibility
8	108	48	4.52	N	11	50
7	155	67	11.20	SW	7	30
10	303	73	12.89	SW	5	30
5	185	61	10.02	NW	8	20
6	578	61	9.04	W	6	16
15	232	72	9.30	NW	7	10
15	544	63	6.60	W	7	10
37	420	75	9.10	N	5	5.2
18	782	75	10.30		5	5.0
8	458	82	12.77		4	2.6
2	946	88	13.30		3.5	3.5
4	586	86	11.79		3.5	1

[1] Aitken, John. On improvements in the apparatus for counting the dust particles in the atmosphere. Proc. Royal Soc. Edinburg, 1889, vol. 16, p. 135.

[2] For a more complete discussion of the dust layers of the atmosphere, see a paper by one of us entitled "The Meteorological Aspect of the Smoke Problem." MO. WEATHER REV., Jan. 1914, 42: 29–35.

Correlation of number of dust particles and visibility.—In Table 1 the dust counts obtained at 8 a. m. at the university up to the end of 1923 only, have been summarized by groups. Group A contains all the counts made during the four cold months December, January, February, and March, the months when most of the coal for heating purposes is burned in Washington. Group B contains the counts made during the months April to November, inclusive, June excepted, when little or no coal is burned for heating purposes.

In these two groups further groupings are made in accordance with the limit of visibility, or the greatest distance at which large objects, such as mountains, hills, buildings, towers, etc., could be seen; and in these subgroups the arrangement is in accordance with the number of dust particles per cubic centimeter of space.

An examination of the averages of the subgroups in Table 1 shows a marked decrease in the limit of visibility with increase in the dustiness of the atmosphere, and indications that the limit of visibility also decreases with increase in the relative humidity.

Aitkin[3] has pointed out that the product of the number of dust particles per unit of space by the limit of visibility is a constant for equal depressions of the wet-bulb thermometer. No such simple relation is shown by the data of Table 1, however, nor should we expect it. The limit of visibility depends upon many factors, such as intensity of the illumination of the object seen, its color, the contrast between it and its background in illumination intensity and in color, light glare in the field of view, etc. Usually the background is the sky, and the presence of dust in the atmosphere decreases the illumination of the object, and also the color contrast between it and the sky, and increases the glare of light in the field of view. But the presence of clouds, and the position of the sun with reference to the object can also produce these same results.

Furthermore, at the American University local smoke may greatly increase the local dust content of the atmosphere above the average in the line of vision to mountains 30 to 50 miles distant toward the west and northwest.

The most distant object seen from the American University is the Blue Ridge Mountain Range, from 40 to 60 miles to the west, and from 1,500 to 3,000 feet in height, although probably under most favorable conditions the Massanutten Range, 70 miles distant, and 3,000 feet high, can be seen. Between the latter and Washington are the Bull Run Mountains, from 500 to 1,000 feet high, and 30 miles distant from Washington.

Unfortunately, until recently, we have not been able to identify different peaks of the Blue Ridge, and therefore when we have been able to see any part of it the limit of visibility has been recorded 50 miles.

To the northwest, Sugar Loaf Mountain, an isolated peak 1,280 feet high and 30 miles distant, is a prominent landmark. Nearer mountains and hills are not so prominent. Near by, the Arlington radio towers and the Washington Monument are prominent. The two points best determined as to distance and most favorably situated for observing are Sugar Loaf Mountain and the Arlington towers.

If we take the product of D, the limit of visibility, R. H., the relative humidity expressed as a per cent, and the maximum value of N, the number of particles per cubic centimeter, through which the point at distance D

[3] Aitken, John. Report on Atmospheric Dust. Trans. Royal Soc. Edin., 1902, v. 42 p. 485.

can be seen, or C = D × R.H. × N, we obtain roughly, C = 480,000, from which, D = C/(N × R.H.). Of course if N is small, this gives a value of D much larger than that observed, but not more discrepant than we would expect from the nature of the data. More refined methods of determining the limit of visibility are needed, and the values of N should be free from local influences.

Diurnal variation in the number of dust particles.—On international days, as designated by the International Committee for the Exploration of the High Atmosphere, and on some others, dust counts were made at noon, or later, as well as at 8 a. m., the results sometimes showing an increase in N during the day and sometimes a decrease. The means for 27 days gives 537 for the average of the a. m. observations and 480 for the average of observations taken at noon or later.

Abnormal variations are sometimes observed. For example, on December 4, 1923, observations at 8 a. m., 10 a. m., noon, 2 p. m., and 4 p. m., gave for N, 2,341, 1,713, 383, 690, and 619, respectively. In this case a light wind from the north with fog shifted by way of east to a fresh wind from the south. Again, on December 12, 1923, determinations at 8 a. m., 10 a. m., and noon, gave for N, 225, 1,427, and 998, respectively. A light southwest wind shifted to the east, bringing city smoke over the university, and then shifted back to south.

Comparison between the dustiness at the American University and in the city.—From May 29 to July 2, inclusive, except on June 12, 13, and 14, the dust counts were made at the central office of the Weather Bureau. The mean of 24 determinations is 522, which is 33 per cent greater than the average for the months of May, and July to October, inclusive.

From the latter part of December, 1923, to March 20, 1924, measurements were made at both the university and the Weather Bureau. The means and extremes for the two stations are as follows:

TABLE 2

Month	Maximum			Minimum			Mean		
	Dec.-Jan.	Feb.	Mar.	Dec.-Jan.	Feb.	Mar.	Dec.-Jan.	Feb.	Mar.
American University	2,403	1,964	1,280	124	97	76	761	533	453
Weather Bureau	6,046	2,546	1,324	248	129	128	1,831	670	603

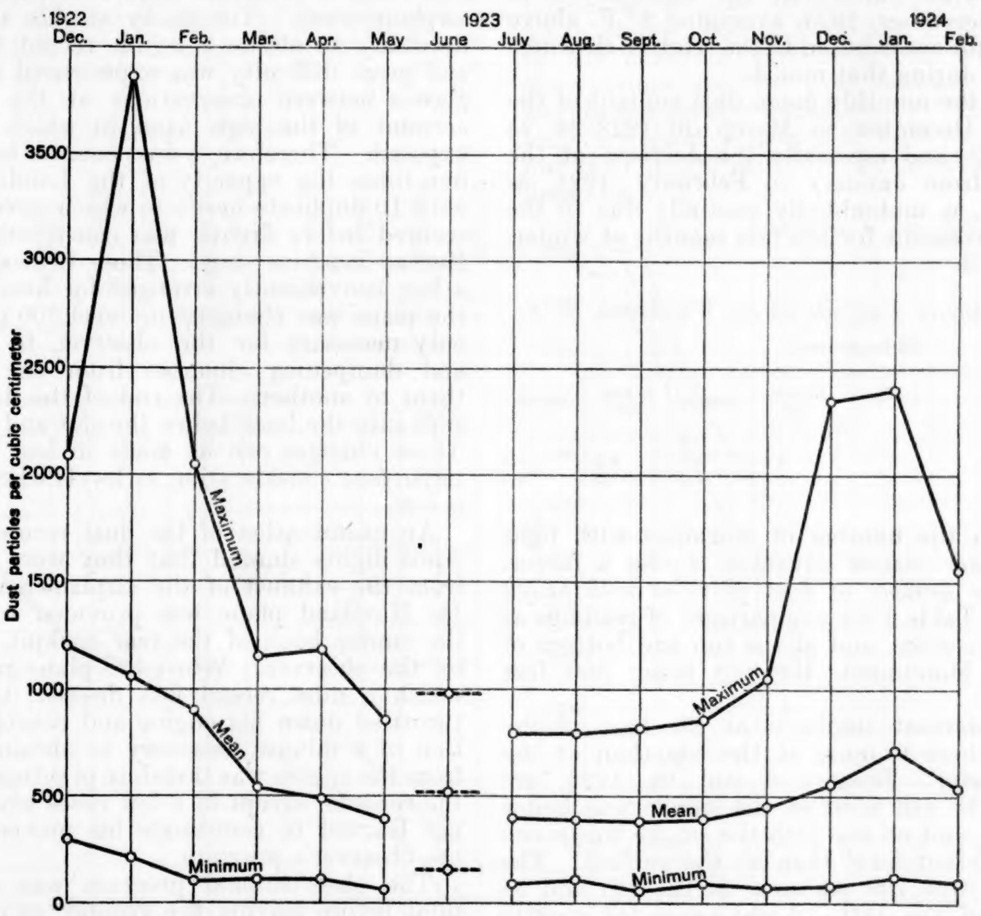

FIG. 2.—Monthly extremes and means of dust content of the atmosphere at the American University, District of Columbia

Comparisons between the dustiness in 1922–23 and 1923–24.—In Figure 2, a decrease in the number of dust particles in the atmosphere at the University is shown in the means and also in the extremes for December to February, 1923–24, as compared with the same months in 1922–23, with the exception of the maximum for December. These figures are significant, in view of the fact that the records of the Coal Merchants' Board of Trade show that from April to December, inclusive, 1922 ,there were received in Washington 218,850 tons of anthracite and 607,047 tons of bituminous coal, or about 2.8 tons of bituminous coal to each ton of anthracite. In January, 1923, 64,126 tons of anthracite and 132,893 tons of bituminous coal were received, or at the rate of 2.1 tons of bituminous coal to each ton of anthracite. From April to December, 1923, and also in January, 1924, 1.8 tons of bituminous coal were received for each ton of anthracite, the total receipts for the whole period being 782,185 tons of bituminous coal and 439.515 tons of anthracite.

The increased receipt of coal in 1923–24 as compared with 1922–23 is, of course, explained by the fact that on account of strikes but little coal was stored during the summer of 1922, while in 1923 storing was general. On account of the shortage in the supply of anthracite coal the use of a certain percentage of bituminous coal in heating dwellings was compulsory during the winter of 1922–23· Inefficient stoking on the part of many householders as well as the increased use of bituminous coal will account for this increased smokiness of the air. Furthermore, during December and January, 1922–23, atmospheric dust records showed a greater percentage of soot, or unconsumed carbon, than in December and January, 1923–24. However, the unusually mild temperatures in December, 1923, averaging 8° F. above the normal, no doubt contributed to the relative clearness of the atmosphere during that month.

The decrease in the monthly mean dust content of the atmosphere from December to March, in 1922–23, as shown in Figure 2, and especially the decrease at the Weather Bureau from January to February, 1924, as shown in Table 2, is undoubtedly partially due to the increased wind movement for the late months of winter, as shown in Table 3.

TABLE 3.—*Average hourly wind velocity for Washington, D. C.*

[Miles per hour]

	December	January	February	March
1922–23	5.9	8.1	8.2	9.1
1923–24	5.5	7.5	8.2	10.0

The decrease in the number of mornings with light winds as the winter season advanees is also a factor.

Variation in the number of dust particles with height above ground.—In Table 4 are comparisons of readings at the American University, and at the top and bottom of the Washington Monument, the top being 500 feet above its base.

Generally the densest smoke is at the base of the monument, and there is more at the top than at the American University. January 8 and 18, 1923, are exceptions. On the 8th most of the smoke was below the 500-foot level, and on the 18th the smoke was much denser at the 500-foot level than at the surface. The relative humidity was 100 per cent on the 8th and 54 on the morning of the 18th. Light snow fell shortly before noon on the 18th. The wind was blowing about 6 miles per hour from the west on the 8th, and about 10 miles from the southwest on the 18th.

TABLE 4.—*Comparison of dust determinations at the American University and the Washington Monument*

	American University	Monument		Remarks
		Base	Top	
1922				
Dec. 26	2,080	2,977	2,616	Dense fog.
1923				
Jan. 5	1,274	2,625	2,560	Visibility 2 miles at base, 3 miles at top.
Jan. 8	878	1,496	259	Haze and smoke at base, clear at top.
Jan. 10	250	676	620	Very clear, visibility 50 miles.
Jan. 13	827	1,209	958	Top only of Arlington towers visible (5 miles).
Jan. 18	515	522	1,230	Visibility 5 miles.
Averages	947	1,584	1,340	

Dust counts from airplanes.—During the winter of 1922 to 1923 observations were confined to the American University and the few taken at the Washington Monument. It soon became evident, however, that like practically all meteorological problems, the examination of the dust content of the atmosphere should be extended to high altitudes in the free air. Arrangements were therefore made by the Chief of the Weather Bureau with the Chief of the Army Air Service for the cooperation of the aviators at Bolling Field in this work. Bolling Field is about 7 miles southeast of the university, on the river front just below the city of Washington.

Two preliminary flights in April demonstrated that the dust counter furnished from London was not adapted to airplane work. Too many strokes of the pump were necessary to obtain a legible record on the cover-glass, and great difficulty was experienced in changing cover-glasses between observations at the different levels on account of the high wind to which the observer was exposed. Therefore, a dust counter having a pump with five times the capacity of the London instrument and with 10 duplicate heads in which cover-glasses could be secured before flights, was constructed in the Weather Bureau machine shop. These 10 heads were secured in a box conveniently arranged for handling. Then while the plane was changing its level 500 or 1,000 feet it was only necessary for the observer to detach the pump and dampening chamber from one head and attach them to another. The end of the dampening chamber slips into the head below the slot and is held by friction. These changes can be made in less than a minute, an important consideration at levels where the temperature is low.

An examination of the dust records obtained on the April flights showed that they were vitiated by smoke from the exhaust of the airplane engine. Therefore a De Haviland plane was provided with pipes to carry the smoke back of the rear cockpit, which is occupied by the observer. When the plane reached a height at which a dust record was desired, the aviator usually throttled down his engine and coasted during the fraction of a minute necessary to obtain a record. Smoke from the engine was therefore practically eliminated from the records, except in a few cases where the aviator had not learned to coordinate his movements exactly with the observer's program.

The observational program was arranged with the pilot before leaving the ground, as communication was difficult during flight. During August records were usually obtained at the 2,000, 4,000, 6,000, 8,000, and 10,000 foot levels during the ascent, and at the 9,000, 7,000, 5,000, 3,000, and 1,000 foot levels during the descent. It was found, however, that after the dust counter had become cooled to a low temperature during the ascent it warmed up only slowly during the rapid descent. Pumping warm air through the cold instrument had the effect of condensing water on the cover-glass as well as on the dust particles. Before some of the records could be counted it was necessary to place them in a box that was heated to a moderately high temperature by an electric lamp for a considerable period of time. Not all the records were made legible in this way, and the means of Table 5 indicate that all records so treated are of doubtful value. During October and November all the records were obtained during the ascent.

TABLE 5.—*Dust records from airplanes*

AUGUST SERIES

Altitudes / Dates	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
A. M.											
Aug. 16	251	-----	384	-----	282	343	172	141	96	72	48
20	372	371	376	404	466	450	366	151	131	70	55
21	292	210	233	269	304	144	89	50	39	32	25
24	200	183	228	189	157	139	180	84	70	-----	59
29	268	200	137	121	105	159	150	93	88	68	52
Means	277	241	272	246	263	247	191	104	85	60	48
P. M.											
Aug. 15	300	323	504	475	445	394	376	-----	-----	-----	89
16	157	-----	292	-----	404	-----	273	-----	81	-----	55
21	251	198	246	233	211	193	191	131	89	50	50
24	221	146	209	177	170	137	159	111	74	27	44
Means	232	222	313	295	308	241	250	121	81	38	60

OCTOBER-NOVEMBER SERIES

Oct. 25	445	282	-----	343	177	139	139	106	75	80	43
26	298	355	379	302	208	139	116	112	73	65	55
29	522	361	222	188	159	84	73	69	53	39	29
30	471	386	345	165	106	55	43	47	37	31	31
31	220	263	277	-----	200	177	100	94	78	59	55
Nov. 2	322	381	322	261	139	75	-----	-----	-----	-----	-----
3	222	129	145	151	110	59	-----	-----	-----	-----	-----
Means	357	308	282	235	157	104	94	86	63	55	43

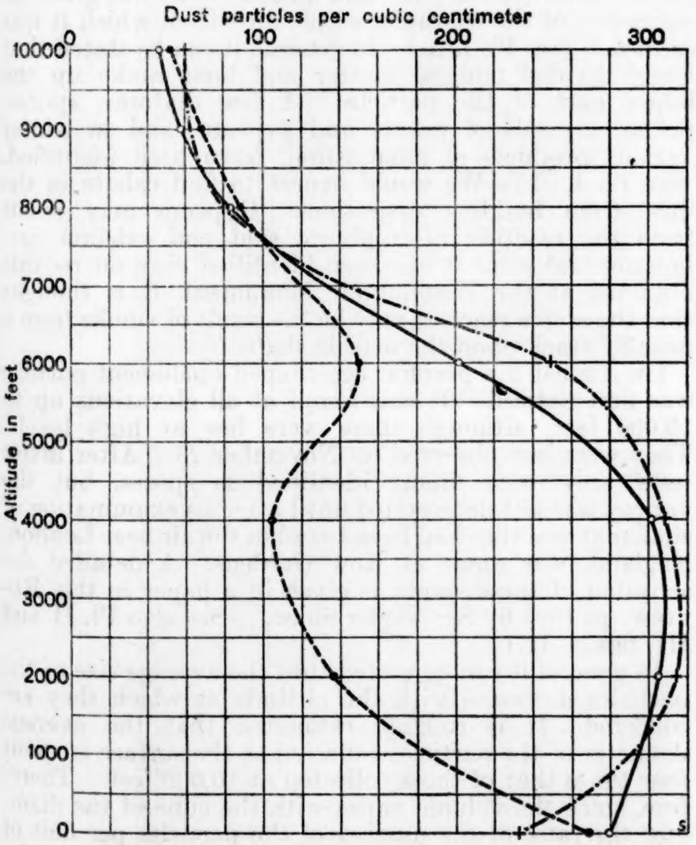

FIG. 3.—Atmospheric dust content determinations during airplane flights, August, 1923. ○, clear sky, a. m.; ✚, clear sky, p. m.; ●, cloudy sky after rain.

The initial flights in April were to 12,000 feet elevation. In August and October, 10,000 feet was the highest elevation reached, except that one flight was made to 14,000 feet to observe clouds. On November 2 and 3, on account of the extreme cold, the flights were to 5,000 feet only, and dust counts were made at 500-foot intervals.

The dust records obtained during airplane flights are summarized in Table 5, and mean results are shown graphically in Figures 3 and 4. Only the measurements obtained during the ascent of the plane have been used in constructing the curves of these figures.

From Figure 3 it will be seen that with a clear sky in the morning (○) there is more dust near the ground and less between 2,000 and 7,000 feet than in the afternoon (+). The increase at high levels later in the day is undoubtedly due to convection. The records obtained on August 29 (●) show the cleansing effect of the rainstorm of the previous night.

From Figures 3 and 4 we note the difference in distribution of the dust in the atmosphere on clear (○) and on cloudy (●) mornings. Often with clear skies there is a noticeable increase in the dust content with elevation up to about 2,000 to 5,000 feet that must be attributed to the effect of vertical convection currents. Visual observations confirm this increase. Thus, on August 20, the observer's notes state: "The ground visibility was very good, and objects were seen with distinctness; but aloft (5,000 feet) the sky appeared to be filled with dense haze."

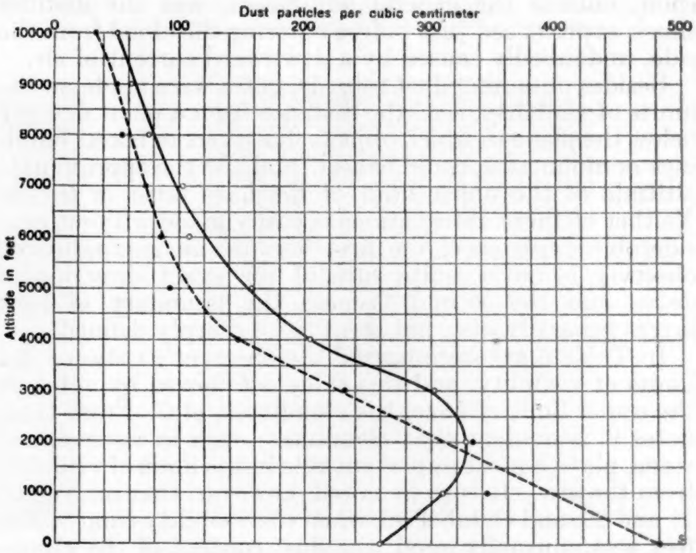

FIG. 4.—Atmospheric dust content determinations during airplane flights, October to November, 1923. ○, clear sky, a. m.; ●, cloudy sky, a. m.

The curves of Figures 3 and 4 may be compared with the curves of Figure 19, p. 49, Monographs on the Theory of Photography from the Research Laboratory of the Eastman Kodak Co. No. 4, Aerial haze and its effect on photography from the air. In this latter figure the curve for January 14, 1919, a. m. (logarithmic type), showing a diminishing rate of increase of haze with increase in altitude, is in agreement with the general decrease in the dust content of the atmosphere with altitude. The remaining curves of this figure (straight line and parabolic types) show the influence of moisture and perhaps other factors as well as dust in the formation of haze.

The time required for a flight has varied from 17 minutes to about one hour. During this time in August the observer was subjected to temperature changes from perhaps 90° F. to 40° F., and in October and November from about 70° F. to 20° F., and at the same time to atmospheric pressure changes from about 30 inches to 20 inches, and to changes the reverse of these. Suitable clothing is sufficient protection from cold except for the hands, but the rapid pressure change is not so easily guarded against. Unpleasant results, such as ringing in the ears, temporary deafness, nausea, etc., sometimes follow.

Full compensation for these disagreeable features is afforded, however, by the wonderful optical phenomena observed above the clouds. At an altitude of 10,000 feet the sky is a deep blue quite up to the edge of the sun's disk. Looking away from the sun a fourfold color effect will be seen. In a layer of purple haze float cumulus clouds, their bases orange or golden yellow, while their summits, above the haze, are a dazzling white against the deep blue of the sky. On days when the upper limit of the haze is well defined the orange bases of the clouds will not be visible in the dark gray haze, while if the sky is very clear, near the horizon it will take on a distinctly greenish shade.

The shadow of one's plane on the clouds below, fringed in spectral colors, is always a beautiful sight.

For pastime, the avaitor sometimes dissipates a small cloud by repeatedly flying through it, mixing its moisture-laden air with drier air, and breaking up the vertical convection current that sustained it.

On August 29 a large cumulus cloud was encountered at about the 3,000-foot level. The aviator drove his plane into it from different sides, going through horizontally, upward and downward. The most noteworthy phenomenon, outside the general bumpiness, was the distinct shock experienced just before entering the cloud from the side, undoubedly caused by a downward current of air.

Besides obtaining dust records, notes were made on the limits of visibility, i. e., the distance from a point directly below the plane to which objects like rivers or lakes, buildings or mountains, could be seen, and also the approximate altitude of the upper limit of the haze layer or layers. Neither of these observations is easily made without considerable experience, the first because an inexperienced observer is never quite sure of the exact direction of *down*, and the second because the boundary of haze layers generally does not seem to be sharply defined.

In Table 6 are summarized the observer's notes on the limits of visibility, and this table is followed by notes on the upper limit of haze, the cloudiness, etc. From these notes it is evident that cloudiness, even in its incipient stage, plays a most important rôle in the limit of visibility from the air. It is to be noted, however, that on August 21 and 29, and October 30, when the visibility from 10,000 feet was unusually good, the dust content of the atmosphere was less than the average. This is not true of October 25, however, with good visibility recorded at all levels.

TABLE 6.—*Visibility, in miles, of land and water surfaces*

Date	Altitude (feet)										
	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Aug. 15, p. m.	10	20	......	......	......	15	......	10	......	......	......
16, a. m.	10	25	10	......	......	......	......	5	......	......	......
16 p. m.	10	25	......	......	10	......	......	10	......	15	......
20, a. m.	10	10	10	10	10	15	10	10	10	10	10
21, a. m.	8	25	10	10	10	10	10	50-60	50-60	50-60	50-60
21, p. m.	10	......	5W, 10E.		......	......	......	......	10 land, 20 water.		
24, a. m.	5	10	......	......	......	20 land, 25 water.			......	......	10
24, p. m.	......	25	Low on account of clouds.					......	......	......	......
29, a. m.	3	10	......	......	......	......	......	......	......	......	60
Oct. 25, a. m.	5	20	25	25	25	25	......	......	60	60	60
26, a. m.	5	......	......	......	......	......	......	......	40 land, 50		river.
29, a. m.	3	......	......	......	......	......	......	......	......	......	[1] 15
30, a. m.	Poor.	......	......	......	......	......	......	......	......	......	100
31, a. m.	8	......	......	......	......	20	......	......	......	......	......
Nov. 2, a. m.	10	15	......	......	......	20	......	......	......	......	......
3, a. m.	8	......	......	......	......	20	......	......	......	......	......

[1] At 14,000 feet.

NOTES ON THE UPPER LIMIT OF HAZE, CLOUDINESS, ETC.

August 15. At 7,000 feet passed through cumulus clouds. Very bumpy. At 10,000 feet the upper limit of the haze was sharply defined. Opposite the sun it appeared as a black line that cut off the view of everything below it, including cumulus clouds.

August 16, a. m. Visibility diminished at 8,000 feet by incipient clouds. Cumulus bases cut off by haze, which was very dark away from sun but whitish under the sun.

August 16, p. m. Haze diminishing in intensity above 7,500 feet.

August 20, a. m. Strato-cumulus merging into alto-cumulus slightly above 7,000 feet.

August 21, a. m. Low clouds diminished visibility. Fr-Cu. at 1,000 feet, cumulus clouds from 2,000 to 4,000 feet.

August 21, p. m. Upper limit of haze not so well defined as usual. To the east it appeared to be in four separate levels, with the boundaries rather wavy in outline.

August 24, a. m. Apparent upper limit of haze 6,000 feet at time of ascent, but about 200 feet higher at time of descent.

August 29. Low clouds made visibility poor until plane passed above them.

October 29. Entered an A. Cu. cloud at 12,000 feet, and passed out of it at 13,500 feet. Ice formed on struts and wings of plane as soon as cloud was entered, but observed the Brocken Specter and fog-bow when looking down upon the cloud from the 14,000-foot level, which indicates that it was made up of water drops, although the temperature was far below freezing. No bumps experienced.

During October and November the time that the plane was in the air was so short that it was impossible to make extended notes.

Character of the dust particles.—Atmospheric dust consists of particles so small that only a few of the larger ones can be examined by the usual petrographic methods. Occasionally an examination of the colloidal material found in the deposit from rain and snow fall has given an indication of the character of the dust from which it was formed. (See Pl. I, A.) In general, it can be stated that finely divided mineral matter and loess make up the larger part of the particles. A few diatoms, spores, pollen, crystals of calcite and gypsum, and in winter various products of combustion, have been identified. (See Pl. I, B.) We would expect to find calcite in the dust from building operations. Gypsum may result from the reaction of sulphuric acid and calcium carbonate; and since it has been identified only on records obtained at the Washington Monument, it is thought that the above reaction may be the result of smoke from a near-by stack upon the marble shaft.

On August 3 a peculiar egg-shaped opalescent particle was first noticed. It was found at all elevations up to 10,000 feet, although there were few at high levels. They were last observed on November 23. After many tests they were finally identified as spores, but the variety was not determined until after an examination of similar spores that had been found in the air near London, England, was made at Kew Gardens. A detailed description of these spores is given in a paper in this REVIEW (p. 139) by Sir Napier Shaw. (See also Pl. II and III, figs. 1-11.)

In general it can be stated that the average size of the particles decreases with the altitude at which they are collected. It is roughly estimated that the average diameter of the particles collected at the surface is about four times that of those collected at 10,000 feet. Therefore, since the volume varies with the cube of the diameter the ratio of the number of the particles per unit of space would have to be multiplied by 64 to obtain the ratio of the volume of the particles at these two levels.

Dust counts away from Washington.—A dust record obtained at the Central Park Observatory, New York, on July 13, 1923, gave 723 dust particles per cubic centimeter, and a record obtained at Long Island City, a

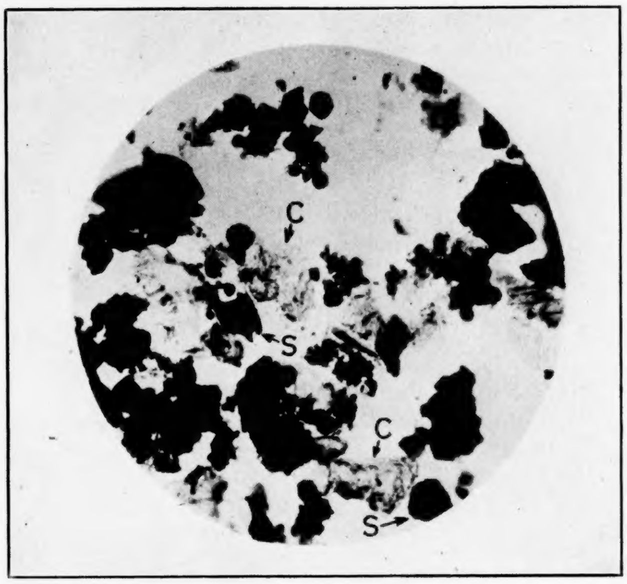

Plate I, A.—Photomicrograph of sediment from melted snow. S, soot, from smoke; C, colloidal matérial

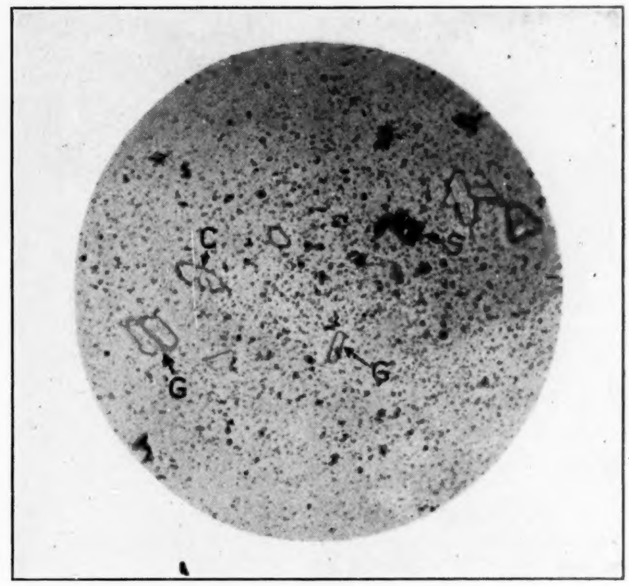

Plate I, B.—Photomicrograph of dust record obtained at the Washington Monument. C, calcite; G, gypsum; S, soot from smoke

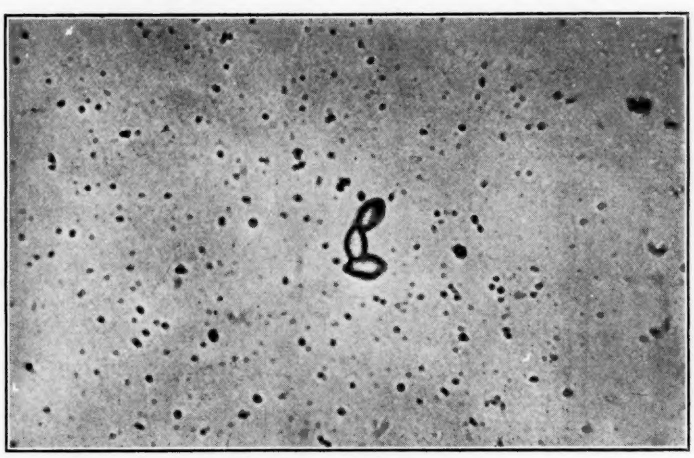

Fig. 1.—October 17, 1923, 8:30 a. m.

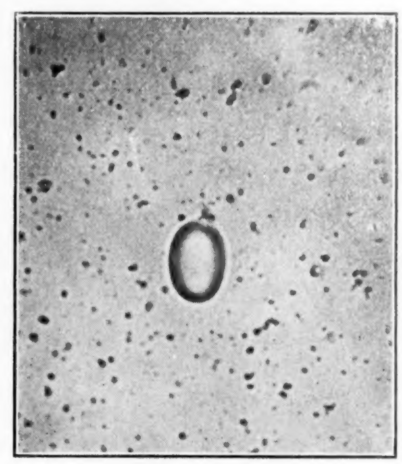

Fig. 2.—October 17, 1923, 9 a. m. Magnification 1,000 diameters

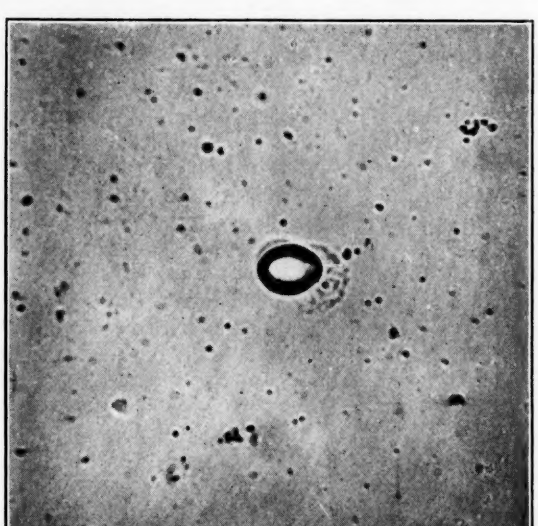

Fig. 3.—October 19, 1923, 8 a. m. Magnification 1,000 diameters. The large organic body is surrounded by a drop of water

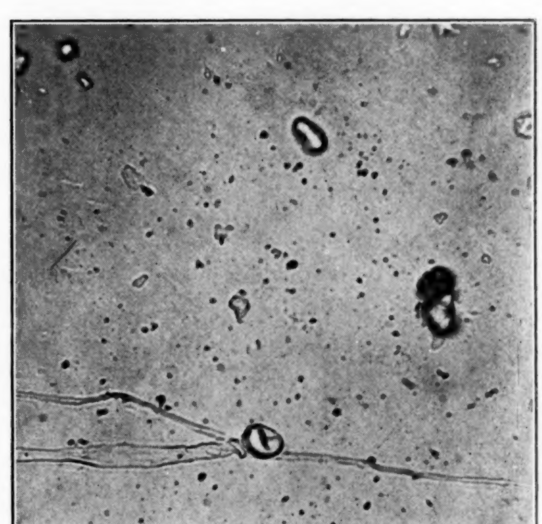

Fig. 4.—October 19, 1923, 8 a. m. Magnification 1,000 diameters. Note fungal hyphæ (?) attached to a body

Plate II.—Photographs of sporelike bodies found in the atmosphere. Taken at Cheam, England

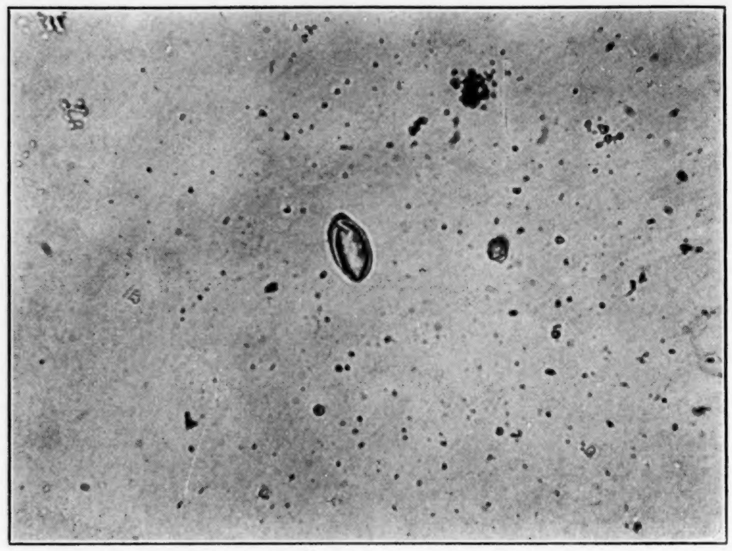

FIG. 5.—From the air at Cheam, October 19, 1923, 8 a. m. Magnification 1,000 diameters

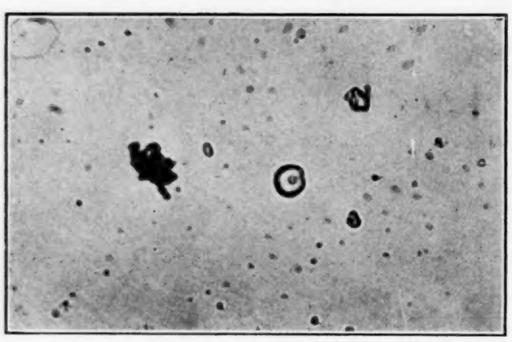

FIG. 6.—From the air at Cheam, October 19, 1923, 9 a. m. Magnification 1,000 diameters

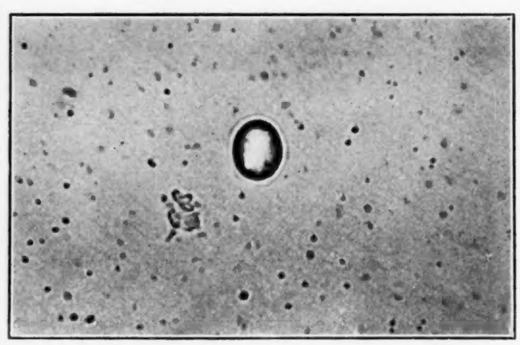

FIG. 7.—From the air at Cheam, October 19, 1923, 9 a. m. Magnification 1,000 diameters

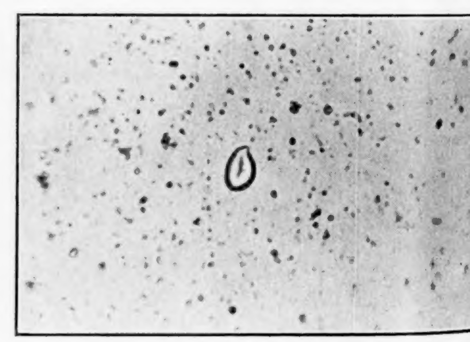

FIG. 8.—From the air at South Kensington, October 20, 1923, 3 p. m. Magnification 1,000 diameters

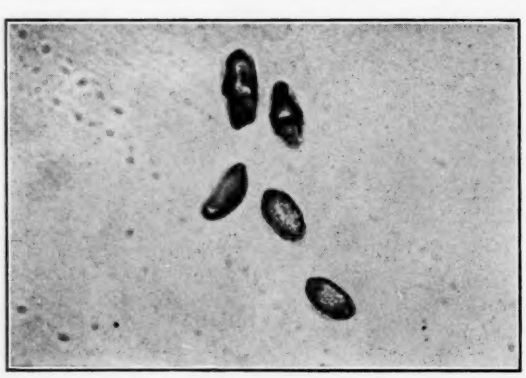

FIG. 9

FIG. 10

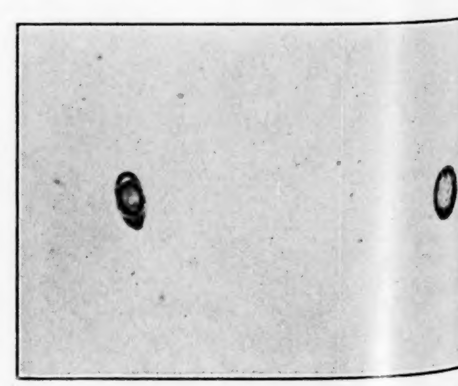

FIG. 11

FIGS. 9, 10, AND 11.—Obtained from fallen leaves shaken above a microscope slide, November 3, 1923. Magnification 1,000 diameters

PLATE III.—Photographs of sporelike bodies

manufacturing center, on the following day, gave 2,036 particles per cubic centimeter.

On September 24 and 25, at about 10 a. m., and on October 11 at 4 p. m., dust records obtained at the Federal Building, in the loop district, Chicago, Ill., gave 6,070, 7,180, and 4,530 particles per cubic centimeter, respectively. Records obtained at Chicago University, in a residence section of the city, at about 8 a. m. on September 24, 25, 26, and at 10 a. m. on October 10, gave 4,800, 3,830, 3,110, and 1,920 particles per cubic centimeter, respectively. On none of these days was the smoke particularly dense for Chicago. Nevertheless the two morning measurements at the Federal Building show a greater number of particles than has ever been found in Washington.

Acknowledgments.—We take this opportunity of expressing our grateful appreciation of the hearty cooperation extended to us, in the execution of the investigations at high altitudes, by Lieut. B. J. Sherry, Meteorological Office, Lieut. L. J. Maitland, operations officer, Lieut. St. Clair Streett, model control officer, and the various other officers from Bolling Field who piloted planes from which observations were made. Without such cooperation, given in a spirit that indicated an appreciation of the problems to be solved, the work could not have been accomplished.

SUMMARY

Surface visibility is a poor criterion of visibility at the ordinary levels of air navigation. After leaving the ground on a morning when objects could be seen at a distance of 20 miles or more, upon reaching a height of 3,000 feet it appeared as though the plane were flying in dense smoke and the visibility decreased to 10 miles.

On the other hand, on October 30, with light fog and poor seeing at the surface, at 10,000 feet the visibility was 100 miles.

The visibility from the air is greatly diminished by clouds even in the incipient form.

The dust content of the air in the city of Washington was markedly increased during the winter of 1922–23 by the enforced use of bituminous coal in heating private dwellings.

While mineral matter, loess, spores, diatoms, and pollen have been identified in atmospheric dust, and also transparent spherical particles of a glassy nature, probably from local furnaces, no dust that appeared to be of volcanic or cosmical origin has been observed.

NOTE ON ORGANIC BODIES FOUND IN THE AIR OF WASHINGTON AND LONDON

By SIR NAPIER SHAW, F. R. S., Chairman of the Advisory Committee on Atmospheric Pollution, London

It was reported on August 25 last by Dr. H. H. Kimball of the Weather Bureau, United States Department of Agriculture, that during the whole of August unusual and comparatively large opalescent particles had been encountered in samples of dust taken in Washington by means of the jet instrument supplied to him through the International Union of Geophysics and Geodesy. These particles had not yet been identified. They were present in large numbers in records taken both on the ground and from an airplane.

At the beginning of September a specimen slide containing some of the particles was received in London from Doctor Kimball. The particles had the appearance of definitely organic structures, some unicellular and some bicellular; they were usually clear, turgid and spherical or oval but sometimes irregular, with as many as nine short but well-defined protuberances. No nuclei could be seen in the cells.

Drawings of the best defined particles were made and these were exhibited by Doctor Owens at the soirée of the British Association in Liverpool.

Somewhat similar particles evidently of organic origin, considered to be pollen grains or spores, had been obtained occasionally by Doctor Owens in records taken in this country at a rural station. The numbers were, however, always very small and no such particles had ever been noticed in records of suspended matter in London.

On October 10, 1923, a record of 1,000 c. c. taken at South Kensington in the usual way was found to contain two large bodies identical in appearance with some of the opalescent particles in the American record. These were single oval cells filled with finely granular matter, each 6 microns long by 3.75 microns wide, with a well-defined papilla at one extremity. The cell wall appeared rough and pitted, and was appreciably thinner at the top of the papilla than at other points. Since this date particles of definite structure have been found in a large number of records.

On October 11 at South Kensington, the bodies were present to the extent of about two per liter. A record taken at 10:15 a. m. contained a perfectly clear spherical body 5 microns in diameter with smooth surface, a similar body with rough and crinkled wall, and a cigar-shaped structure divided in the middle and containing two definite oval cells. The latter was not turgid but bent over in the middle.

When water was introduced under the cover slip, the cigar-shaped particle immediately became turgid and apparently split open near one end. The length of the extended particle was 10.8 microns. The center partition dividing the body into two equal cells was well defined.

A small quantity of a solution of gentian violet was introduced under the cover slip. The cigar-shaped particle and the sphere with the rough wall at once took up the stain and became almost black, but the clear sphere was unaffected.

Further records were found to contain similar oval and spindle-shaped particles, which readily took up the stain when mounted in blue glycerin jelly.

A number of records have since been taken at different hours, from which it is concluded that the organic particles have not been present at all times of the day in London. For instance, records taken in Bloomsbury on Sunday, October 14, at 1 a. m. and at 12:15 p. m. contained no definite organic structures, but many square and hexagonal crystals, some of which were quite well formed.

Again, at 8:30 a. m. on October 17, records were taken simultaneously at Cheam, near London (fig. 1, Pl. II) and at London, in Bloomsbury. The record at Cheam contained at least 20 definitely organic particles per liter, generally oval in shape and up to 12 microns in length, together with approximately 630 smoke particles per c. c. whereas the London record contained only 5 or 6 such bodies, and all less than 5 microns in length. The number of smoke particles shown by the London record was approximately 5,000 c. c. The organic particles from the air of Cheam on this occasion were of particular interest. Three roughly oval cells, each about 4 microns

long by $2\frac{1}{2}$ microns wide were found actually connected together end to end and the two end cells showed signs of further subdivision by a pronounced thickening of the walls about the middle. (Fig. 1, Pl. II.) Another body took the form of a single oval cell 10 microns long by 5.7 microns wide, full of clear colorless matter. (Fig. 2, Pl. II.) The cell wall was smooth and at one extremity there was a very well-defined papilla, giving the whole a shape rather like a lemon. Another somewhat cylindrical cell 12 microns long by 3.3 microns wide bore side markings suggesting points of attachment to other cells, which gave it an appearance resembling a portion of a cabbage stalk stripped of the leaves.

Yet another cell, roughly square with a side of 5.8 microns, contained a reddish-brown ball of 4 microns diameter with rough surface—possibly a zygospore.

Photographs of particles obtained on other occasions are given in Figures 3 to 8, Plates II and III.

The volume of air passed through the instrument in taking the above records was in each case 500 c. c.

A further record taken on the same day in Westminster shortly after 4 p. m. contained a clear oval body 6.7 microns long by 3.3 microns wide, on which appeared six small budlike protuberances, irregularly spaced on the surface. At 4:30 p. m. five of these appeared equal in size, the sixth being much smaller; 15 minutes later two of the processes had practically disappeared, while two of the remaining had appreciably increased in size. At 4:50 p. m. four processes remained, one of which had still further increased. Forty minutes later the smallest protuberance which had hitherto remained unchanged was found to have disappeared and its former position was marked by a small black particle not more than half a micron in diameter, just appreciably separated from the main body, suggesting at first sight that the process had not become completely severed. It is, however, more probable that the black spot was a smoke particle at first unnoticed owing to its being hidden by the process which had now been withdrawn into the main cell. Of the three remaining, the largest process had further appreciably increased since 5 p. m. and took the form, roughly, of a hemisphere of radius somewhat less than 1 micron.

On the morning of October 18, the oval body remained as a single cell with no protuberances, unaltered in size within the limits of accuracy of measurement.

This cell appeared to be not quite turgid and the former positions of two of the processes were marked by the light irregularities in its outline. Beyond this no traces remained, but the single smoke particle near the body, already referred to, was visible. It is thus probable that the rapid changes first noted in the appearance of the body may have been due to loss of water by evaporation owing to the focussing upon it of heat rays by the illumination of the microscope.

The slide was gently warmed by placing it under the microscope lamp for four hours, but no resulting change in appearance of the body was detectable.

ORIGIN OF ORGANIC PARTICLES

The occurrence of particles unlike anything previously noted, either in America or England, appears to suggest a common origin, and the fact that they occurred in greatest numbers during exceptionally wet and windy weather precludes the possibility of their being dust particles raised from the ground. Again the difference in the number of particles present in London and at Cheam, in Surrey, at the same time points to some local source.

The most probable explanation appears to be that they are spores of some fungus, the growth of which has been favored by the wet weather. A portion of a whitish mold—probably mucor or crystopus—found on a fallen apple at Cheam was examined and found to contain a large number of readily stainable globular cells, similar in size to those obtained in the records.

In size and all other respects, the organic bodies correspond with spores of almost any mildew, rust or smut, which, according to one textbook "flourish in proportion to the wetness of the season or the dampness of the locality." Spores of corn smut and grass smut, and indeed of most of the Ustilaginaceæ correspond closely with the particles found, as do also the conidia of white rust.

Many of the spores of the Ustilaginaceæ are colored, and may possibly account for some of the isolated colored, spherical particles which have been occasionally found in previous records, although it is known that colored glassy spheres are also produced in furnaces.

Conidia of white rust (*Cystopus candidus*) are normally of about 13 or 14 microns in diameter. In the presence of moisture these swell and at one extremity of each there is produced an obtuse papilla. Vacuoles are formed in the contents of each conidium and the protoplasm becomes separated by fine lines of demarcation into five to eight portions, which develop into zoospores in the course of from one and one-half to three hours. If not immersed in water, the conidia of Cystopus may remain unchanged for as long as a month.

Thus every kind of definitely organic particle encountered may be explained on the basis of spores of micro-fungi, and the recent abnormal increase in their number may be the outcome of weather conditions particularly favorable to their development.

It is probably more than a coincidence that these mold cells appeared in the autumn apparently for the first time, or at least were detected then for the first time, and one naturally looks for something which occured in the autumn and not at other times of the year to account for this. The fall of the leaf is one of the most obvious signs of autumn and when the leaves are dead and exposed to continuous damp they are likely to grow molds of different kinds.

One can easily conceive of threads of mold cells growing up from the surface of dead leaves and the terminal cells of spores produced, being swept away by the wind. Also when the leaves have fallen they are carried about in the wind and rubbed against each other, so that any mold on the surface is more than likely to become detached and set free in the air.

To test this hypothesis Doctor Owens selected a number of dead leaves from the trees in the neighborhood of Cheam and on examining these under the microscope there was evidence in some of them of mold but not in any quantity. The leaves were dry at the time and possibly it would have become detached but in the angle between the midrib and the lateral ribs of the leaves at the back there were in many cases masses of white threadlike material. A piece of one of these leaves was placed on a drop of water under a watch glass and within 12 hours a plentiful crop of mold had appeared with branched threads of spores.

The possibility of fungi growing on the blotting paper lining the walls of the dampening chamber of the instrument has not been overlooked. Records were taken for comparison using a damping chamber freshly prepared with new blotting paper. The result in each case was the same and no growth whatever could be detected on

the old blotting paper after removal from the instrument.

It appears probable, therefore, that dead leaves were the chief source of the mold cells found in the air.

As a further test, on October 29, a disk was cut from a leaf of suitable dimensions to fit in the jet dust counter; this was sterilized by boiling; a record was taken on it by drawing 1,000 c.c. of air through at 9 a. m. and the disk of leaf placed under a glass in a drop of boiled water in a dark place.

A similar test was made on October 30 but the result of the experiment was negative. This, of course, may be due to the absence of spores in the air when the records were taken, and as a matter of fact records taken at the same time and examined microscopically did not show any spores present. It appears, however, fairly certain that the origin of the mold cells is as indicated, that is, from the dying leaves in the autumn, the conditions being very suitable.

The following test was made, which points directly to this source:

A number of dead leaves taken from the trees in the neighborhood of Cheam were placed in a tin box on the bottom of which a wet cloth was placed, and above the cloth a microscopic slide, the leaves being placed above this. After a couple of days the slide was removed, the leaves having been agitated slightly, and on examination under the microscope it was found to be covered by cells identical in appearance, dimensions and shape with those referred to as having been obtained from the air. (Figs. 9–11, Pl. III.)

The presence of these mold cells in the air in large numbers during the fall of the leaves may have some pathological significance, but what it is the author is unable to suggest at present. As a rule mold cells are nonpathogenic but it appears possible that they may have some effect which has not previously been realized.

THE DUST FALL OF MARCH 29, 1924: A PRELIMINARY NOTE

By ERIC R. MILLER, Meteorologist

This dust fall was detected at Madison, Wis., on the afternoon of March 29, 1924, by the author, some of whose studies, in collaboration with Dr. A. N. Winchell, have appeared in this REVIEW [1] and elsewhere.[2]

So generous have been the responses to our requests for cooperation that we have been provided with more samples of dust for analysis, and more reports showing the distribution of the dust than we have had for any previous dust fall.

Sixteen Weather Bureau stations in Nebraska, Iowa, Minnesota, Illinois, Missouri, Indiana, and Michigan, among 26 to which telegrams were sent from Washington by Supervising Forecaster E. H. Bowie, reported finding dust in the rain or snow. Mr. A. M. Hamrick, at Davenport, Iowa, secured the repetition of the request by radiophone from broadcasting station "WOC" and obtained 30 positive replies and 8 samples of dust from listeners in Iowa, Illinois, Missouri, and Wisconsin. A similar request sent out from "WHA" at Madison was interfered with by static and brought only a few replies. Postal-card inquiries addressed to directors of climatological sections in all States east of the Rocky Mountains brought reports of dust-raising winds in Texas, Oklahoma, Kansas, and Arkansas, of thick haze in Kentucky and Tennessee and of dust falls in the same list of States as that given above. No dust falls were observed east of Michigan and Indiana nor south of Tennessee. The most copious samples were taken in the upper Mississippi Valley.

The mechanism by which the dust was raised, transported, and deposited can be most easily understood by reference to the weather maps for March 28 and 29, 1924, and to the diagrams of storm structure due to Shaw [3] and Bjerknes.[4] The dust was blown up from the ground by the "sirocco" that formed the southern sector of the storm and carried northeastward against and up over the flank of the cold "northeaster" that hugged the ground north of the "steering line." Rain and snow produced by mechanical cooling in the ascent of the warm air washed down the dust, bringing it to earth in the "rain stripe" that characterizes the cold "northeaster" of every cyclone.

At Des Moines, Iowa, Springfield and Peoria, Ill., the dust was washed down in rain. North of a line through Davenport and Chicago the precipitation was in the form of snow. The percentage of dust diminished with distance northward until it became so scanty at Duluth as to be found with difficulty.

It is proposed to procure thorough and exact chemical, mechanical, and microscopical analyses of the dust in the laboratories of the University of Wisconsin. A grant of $200 has been requested from the research fund of the University of Wisconsin to defray necessary expenses in making analyses.

The most important things that it is proposed to study are (1) data that will be useful in interpreting the loess deposits of the glacial period, (2) the enrichment of the soils of the upper Mississippi Valley by dust blown from the more alkaline soils of the Southwest, and (3) the bacterial fauna accompanying the dust.

Information on the third of these points has already been supplied by Dr. J. G. Dickson of the department of plant pathology of the University of Wisconsin, who has germinated spores of various rusts and fungi from material that he collected on the afternoon of March 29, 1924, while the dust was still falling. He found the spores in the dust to be in a state that will not be reached by local spores until late in May, i. e., nearly two months farther advanced.

Previous analyses of dust falls have indicated that the present rate of deposit of dust from the atmosphere is much slower than must have prevailed in the glacial period. The samples from the present storm will not advance this information greatly for the reason that only those taken at Madison, Wis., and Windsor, Wis., a near-by village, were collected from measured areas of snow. If future dust falls deposit dust at the same rate, it will indicate that storms of the same type as that of March 29, 1924, were much more frequent in the glacial period than at present. This seems to be a reasonable deduction, since according to Bjerknes they tend to follow the "polar front" which is necessarily associated with the margin of the polar cap of snow, because the snow surface and the air above it are much colder than the air over bare ground. In the glacial period when this margin remained in these latitudes instead of retreating far to the northward as at present, it seems probable that "Colorado" storms were more frequent, and that dust was more continuously deposited. For these reasons it also seems probable that the loess was deposited in glacial rather than in interglacial epochs, as some geologists have suggested.

[1] Dust falls of March, 1918. MO. WEATHER REV., 46: 502.
[2] Same, *American Journal of Science*, 46: 599.
[3] Forecasting Weather, Washington, 1911, fig. 96, p. 212.
[4] Structure of the Atmosphere when Rain Is Falling. Q. J. Roy. Met. Soc. 46: 128, and also MO. WEATHER REV., 48: 401, July, 1920.

THE LAVA TIDE, SEASONAL TILT, AND THE VOLCANIC CYCLE

By T. A. JAGGAR, Volcanologist, assisted by R. H. FINCH and O. H. EMERSON

[Volcano House, Hawaii, January, 1924]

I. *The lava tide.*—Chamberlin has written "pronounced tidal movements might be expected in the necks of volcanoes if they were connected with large reservoirs of lava below, but if there is any response to tidal strains at all, it is scarcely detectable."[1] In July–August, 1919, at the Hawaiian Observatory the authors investigated this question for a month, assisted by Messrs. Sumner Roberts and Charles Thorndike.[2]

The work was stimulated by test measurement made by Mr. Jaggar January 4, to 14, 1913, at Halemaumau lava pit. A telescopic alidade was set up on sill of instrument shelter built at pit's edge and numerous vertical angles were read for 10 days to measure hourly change of level of liquid lava pool against a vertical portion of its shore line. It was found that there were variations in lava level of from 1 to 6 feet per hour sometimes up and sometimes down. For four days forenoon levels were low and night levels were 5 to 10 feet higher. During a run of 22 hourly readings January 7 the lava rose and fell in pulsations suggesting a six-hour periodicity, the risings sudden and the sinkings slow, with culminations around 12 or 6 o'clock both night and day.

On July 21, 1919, transit measurement every 20 minutes for a month was instituted, Messrs. Jaggar, Finch, Emerson, Roberts, and Thorndike each taking turn in shifts, and making readings on a rim station as datum. Two points on the edge of the liquid lava lake and two points on the pit floor or "bench magma" were incessantly measured with reference to the datum station horizontally and vertically, and the index error of the level bubble was always read. Releveling was frequent as the instrument shelter was itself one of the moving points on the floor, the ground rising during the month. All of this was inside the inner pit Halemaumau of Kilauea Crater, and the shelter was placed near the margin of one of three inner lakes of lava. A triangulation was made every day to locate shelter and floor movements.

From the observatory 2 miles away occasional readings were made to check possible small fluctuations in height of the datum station, and daily readings were made with micrometer telescope on the lava crags that rose above rim of Halemaumau. These distant observations furnished a check wherewith to observe sudden changes or accidents to the datum station. No significant movement of that station occurred. The lava in Halemaumau was very high, the floor area standing as a dome mostly above rim of pit, with the three lakes in clover-leaf pattern as cups or wells puncturing the crest of the dome. Notes on the beginning and ending of the field work will be found in Bulletin of Hawaiian Volcano Observatory under the dates July 19 and August 18, 1919, and illustrations showing conditions, transit shelter, etc., are published in the July, August, and September Bulletins of that year. During the 28 days of measurement beginning July 21 the lake rose 58 feet to August 15 and sank 29 feet thereafter: August 2 to August 12 rather stationary conditions prevailed. The floor rose 50 feet to August 16 and subsided thereafter 6 feet.

It should be explained that floor and pools are both parts of the live red-hot lava column, the floor being covered with a heavy crust that is a heat insulator. This floor lava is a stiff but mobile magna rising by mass tumescence. The liquid lava in cups of the floor rises through wells in the floor substance by gas foaming and maintains shallow pools, apportionate in size to the heating or melting capacity of the gassy flux. The rim of pit is old rock somewhat crevassed and sometimes forced into tumescence by the paste occupying the crevasses below, but in general relatively rigid. It acts as a definite cold boundary or "perilith" for the mobile lava column.

Results of the measurement referred to fixed datum have been plotted for the entire period, and by taking the mean of overlapping five-point summations hourly levels for the liquid lava and the floor lava have been computed. The curve of 20-minute intervals shows a ragged rise and fall of both liquid lava and floor lava, the liquid ranging from zero to 2 feet or more in 20 minutes, the floor from zero to a half foot more or less. The curve develops a crude semidiurnal fluctuation for the liquid ranging from 2 to 7 feet with sharp bends, and a sinusoidal diurnal curve is indicated with a range of from 3 to 5 feet. For the floor lava the curve is made up of flat arching movements running for from 4 to 6 hours each, and compounded into pronounced diurnal sinusoidals with a range of about a foot. These diurnals show best August 2 to 12 when the longer term rising movement tends to flatten out to something approaching stationary lava.

These facts may best be seen by reference to the figures. Figure 1 shows actual results of measurements of the liquid lava fluctuation at 20-minute intervals from 7 p. m. July 24 to 7 p. m. July 28. There is here indicated a definite diurnal rise and fall with the rising movement enduring longer than the falling movement as the net change for the four days was a marked rising of the lava column. It will be seen in this figure also that a semidiurnal movement is strongly suggested.

Figure 2 exhibits the lava movement August 6 to 11. Curves A and B show the liquid lava, C and D the floor lava. Curve A is the diagram of hourly measurements arrived at by overlapping summations. Here pulsations of gas action are evident and from noon to noon there is at first sight little trace of diurnal periodicity. The diurnal characteristics of this portion of the liquid curve show better when we examined by overlapping means the record for eight days. This has been done in curve B. This curve was arrived at by taking, for example, the average movement from noon to 1 p. m. for the five days immediately adjacent to each date; thus for August 6 the average of August 4 to 8, inclusive; for August 7 the average of August 5 to 9, inclusive, etc. The same treatment was accorded the average movement from 1 p. m. to 2 p. m., from 2 p. m. to 3 p. m., etc., so that the curve for the four days really represents an averaged curve for eight days. It is at once seen that a systematic diurnal rise and fall occurs with low levels about 10 p. m. and high levels in the morning. A striking character of the diurnal curve here is its powerful oscillations from about midnight on, decaying or dying away along with subsidence the following afternoon.

The rise and fall of the floor lava (C and D of fig. 2) is represented at C by the 20-minute measurements, reduced to hourly, and at E by the hourly reduced by the five-day overlapping process. In both of these the diurnal rise and fall is very plain with low levels usually in the forenoon and high levels in the night.

Comparing A–B, the liquid, with C–D, the floor, it is evident that the two sets of waves are not in phase, especially for the first three days with respect to the troughs or low levels indicated in this figure. The B

[1] T. C. Chamberlin, The Origin of the Earth, p. 231, University of Chicago, 1918.

[2] Bulletin Hawaiian Volcano Observatory, July to September, 1919.

curve moreover agrees generally in its times of low and high with the facts indicated in Figure 1 representing a period two weeks earlier. And at that time also there was disagreement in phase between liquid and floor, not here figured.

Summing up the facts available we see that these measurements reveal the extraordinary truth that a systematic tide lifts the lava in Kilauea Crater so that for the dates indicated the liquid is high in the morning and low in the evening, and the inner floor is high in the night and low in the forenoon. The range of movement is greater for the liquid than for the floor matter. And finally, it appears from Figure 2 that a gradual rising movement of floor matter begins a half-day, more or less, before the corresponding upward spurt of gas and liquid, and then the floor sinks rapidly to its lowest position a half-day before the gradually subsiding liquid lava reaches its minimum. The two maxima are much closer together than the two minima.

II. *Seasonal tilt.*—At the 1920 meeting of the pan-Pacific conference the writer presented results of tilt measurement with seismographs to show that at Kilauea Volcano excessive tiltings occur, that resolve themselves into decaying quarterly series of monthly waves, with mean directions away from and towards the Mauna Loa center of the Hawaiian volcanic system. It was found that rapid forced movements away from the centrum exhibited accordance with subsequent lava risings, and a reverse movement accorded with sinkings.[3]

Prof. Leo Cotton commented as follows (Pan-Pac. Proc. 1921, p. 324): "Tilt instruments installed in Australia show very large seasonal tilts. A tilt of 5 to 10 seconds' range occurs from winter minimum to summer maximum. The period of the tilts lags several months behind the heat effects. The instruments are placed about 30 feet underground. The tilt records at Kilauea need a year's work to see how the data compare."

The curve of tilt more than three years, 1919–1922, at Kilauea Obervatory, is shown in Figure 3. This is the east-west component, involving directions away from and toward Mauna Loa center. In addition to the above-mentioned short-term waves, more strikingly monthly than quarterly, a marked annual wave of 15 to 25 seconds' tilt accumulation appears, the east movement culminating in winter (December to March) and the west movement in late summer (August to September). Something of the quarterly decay curves exhibited in 1917–18 (pl. 22, Bull. Seis. Soc., December, 1920, v. ante) are shown again in autumn and winter 1919-20. The annual curve is sinusoidal except in 1919 when the September bend is sharp. At the end of this month Mauna Loa broke into violent eruption.

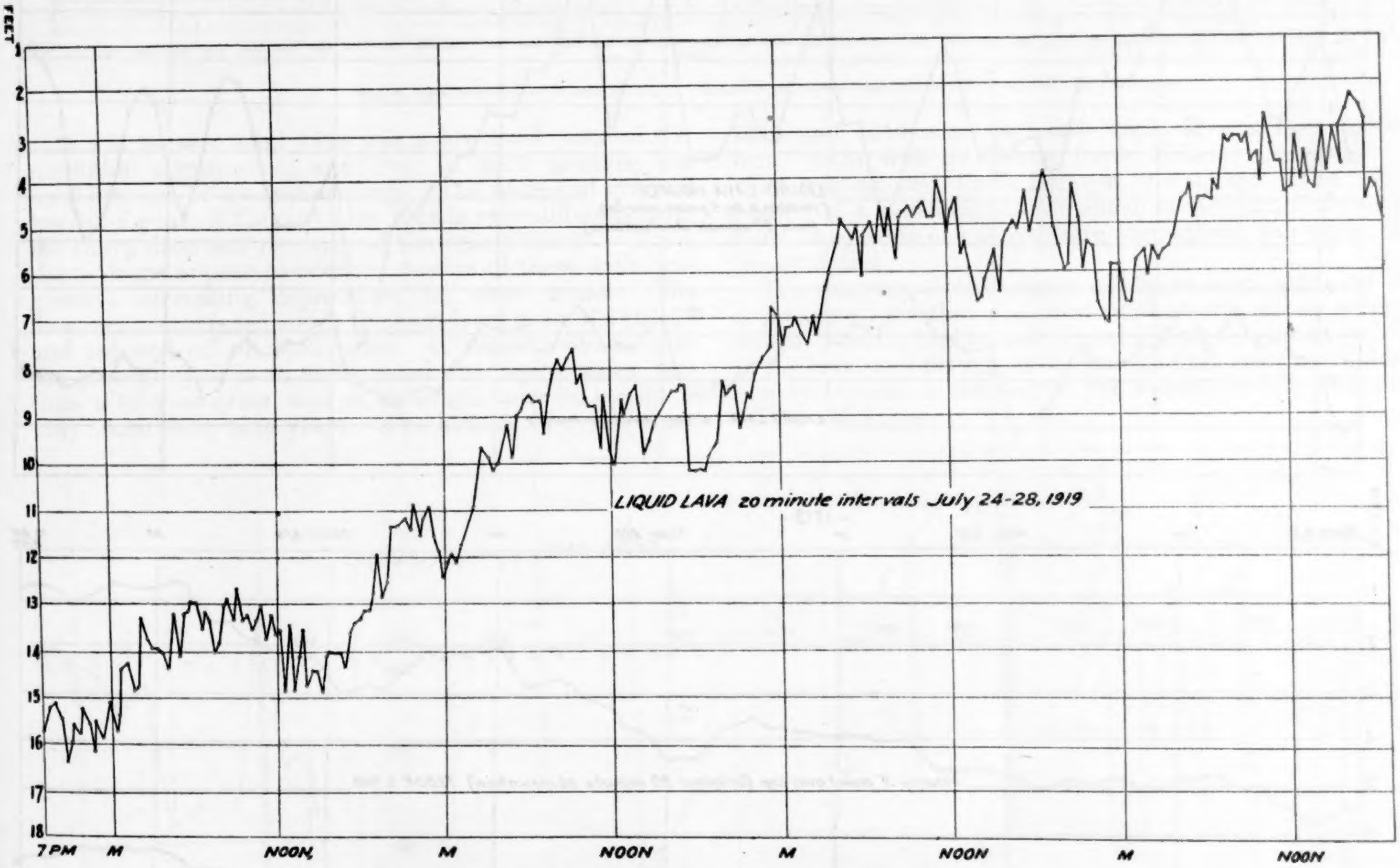

FIG. 1.—Liquid lava fluctuation at Kilauea July 24 to 28, 1919, at 20-minute intervals

This curve supplements previously published data by showing winter tilt waves of wide range and monthly period with accumulation east, and summer decay to short range waves of shorter period with accumulation west. How may this be tied to the volcanic phenomena? In the paper above cited (Seis. Soc.) the writer has exhibited seasonal lava fluctuation centering about equinox. In the first part of the present paper he has shown the presence of daily lava tides.

It is too early in the development of volcano science to present theoretical correlation of these rhythms. This much may be pointed out in comparing volcanic effusion of the Hawaiian system with the tilt in Figure 3. In spring of 1919 Kilauea flooded voluminously with some decline in September. (See fig. 4.) In autumn

[3] Proc. First Pan-Pac. Sci. Conf., Honolulu, 1921, p. 319, and Bull. Seis. Soc. Amer., vol. 10, No. 4, p. 201, December, 1920.

to winter 1919–20 Mauna Loa and Kilauea produced two immense lava floodings. In August, 1920, all of this declined. In winter 1920–21 Kilauea flooded vigorously. In July to August, 1921, this had declined. In winter 1921–22 Kilauea lava rose to a May culmination and outbreak, in craters that had been quiet for 82 years. This was followed by tremendous subsidence *with recovery in September, 1922.* The whole period 1919–1922 shows declining annual tilt and subsiding lava.

ill defined. The Hawaiian system involves four potentially active volcanoes liable to intrusion or extrusion, and an indefinite sea-bottom tract of unknown volcanic proclivities.

The nine-year cycle in Hawaii, however, has been satisfactory for the last three decades, with culminating eruptions on Mauna Loa in 1899, 1907, and 1916–1919. It is now of interest to examine a chart (fig. 4) showing quarterly culminations (highest levels) of Kilauea lava

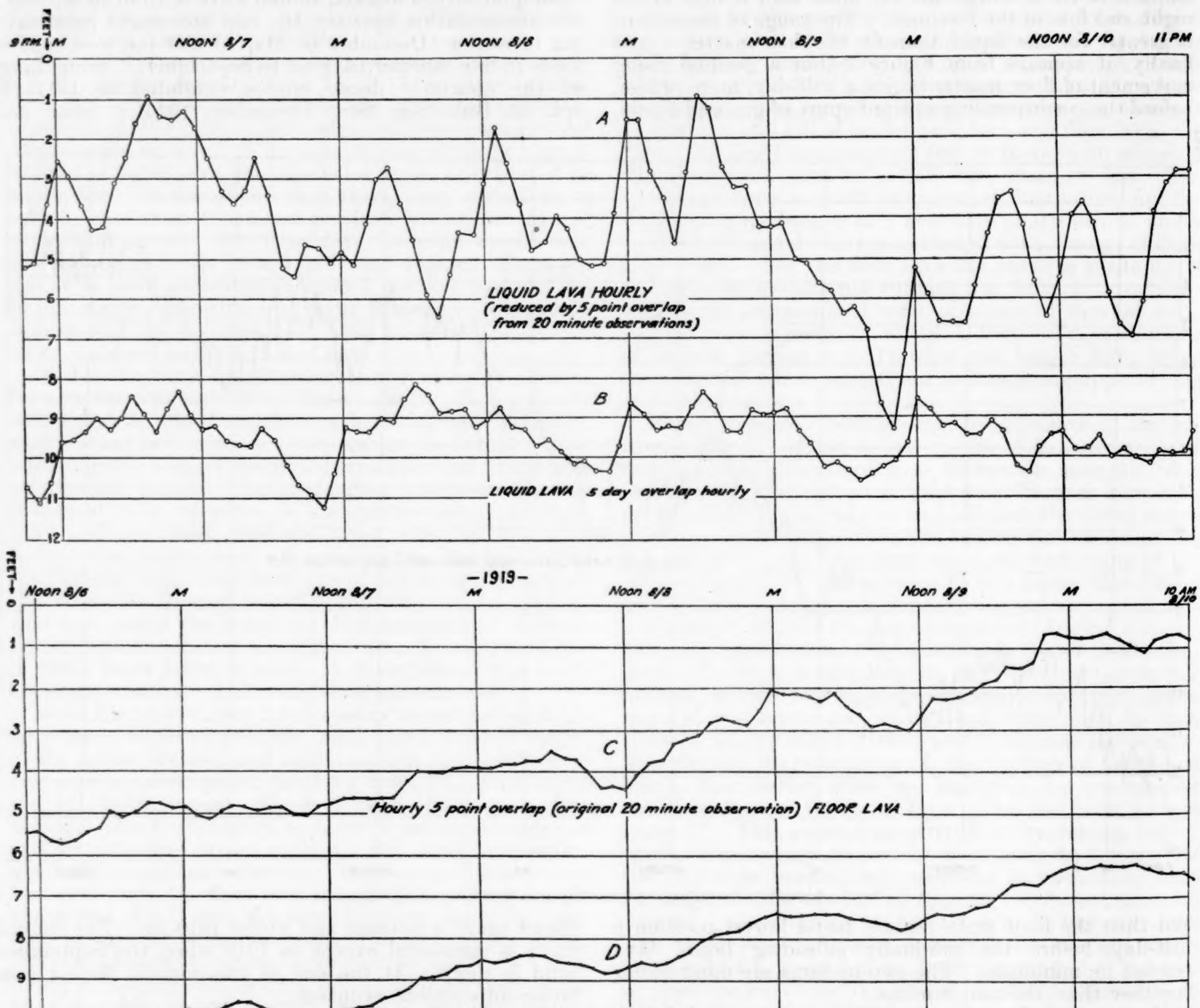

FIG. 2.—Liquid lava and floor lava fluctuations at Kilauea inner pit August 7 to 10, 1919. A is liquid lava hourly; B is same curve smoothed by overlapping summations, inclusive, of eight days; C is floor lava hourly; D is same curve smoothed by overlapping summations.

III. *The volcanic cycle.*—W. L. Green in his "Vestiges of the Molten Globe" (Part II, p. 287) concluded that a nine-year period was the "full" period for the Hawaiian eruptive cycle, but that frequently the periods were shorter. Phillips, Mercalli, and others have experimented with Vesuvian periods, and have encountered difficulties. The trouble is that the volcanic *system* that demands extravasations is likely to be geographically

for 14 years past, with every measurement since the summer of 1911 under the supervision of the Hawaiian Volcano Observatory.

The quarters are centered about the months March, June, September, and December so as to concentrate solstice and equinox. *Highest level* for the three months, including one month on each side of the month named, is what the curve shows. The black vertical lines

indicate the low limit reached by one or more pronounced subsidences, which sometimes happened *within* a three-months' period. Sudden risings within a quarter are indicated by broken lines. MF and KF mean, respectively, "Mauna Loa flowing" or "Kilauea flowing," including both flank outflows and voluminous flows within the greater craters.

1868 indicates that there were two of 12 years' duration, with an average of 8.5 years.

One remarkable character of the 1913–23 cycle should be stated and then this paper is finished. That is the sequence to date of outflow vents progressively lower on the mountains. 1914 produced eruption in summit crater of Mauna Loa, elevation 13,000 feet.

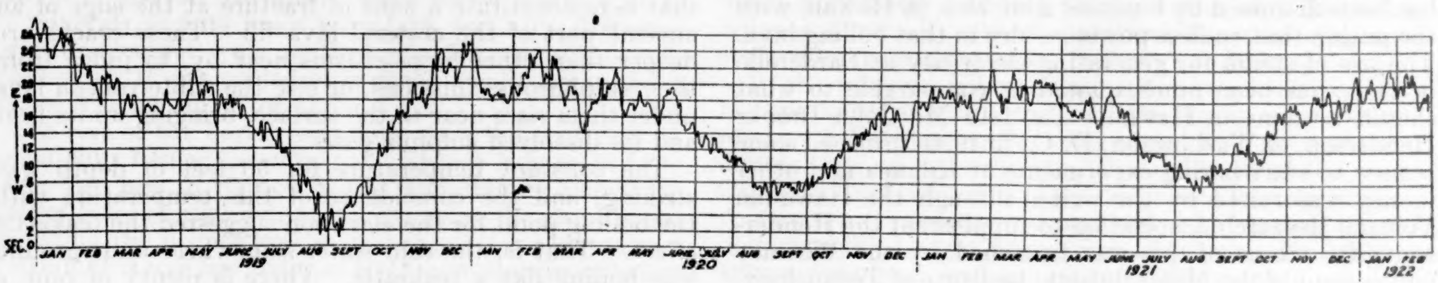

FIG. 3.—Curve of east-west seasonal tilt at Kilauea Observatory from 1919 to 1922, from daily measurements

It will be seen that 1913 was a low-level year of remarkable significance, and that in 1923 another low level appears to be approaching. The wide and gradual low-level peak of the curve for 1913 is very different from the sharp drop and recovery of the year 1922–23. These sharp drops appear to occur in groups of three with progressive increasing depressions for each triplet. The flowing concentrated about the high-level peak of 1918–20 and tapered off on both sides. It seems probable that the present cycle is an exceptional one, representing perhaps a 60-year crisis, and so its length may be considerably more than nine years. The history of cycles since

1916 and 1919 were on south flank Mauna Loa, 8,000 feet. 1920 was on south flank Kilauea, 3,500 feet. 1922 was on east flank Kilauea, 2,500 feet. The suggestion of a subsiding subterranean lava column, seeking relief in spasms of gas pressure throughout the cycle, is unavoidable.

The purpose of this paper will have been achieved if it demonstrates that the crust of the earth at an active volcanic belt is highly mobile, exhibiting tides and cycles in the lava, and tiltings of the ground that are remarkable and systematic in relation to the seasons and in relation to the volcanoes.

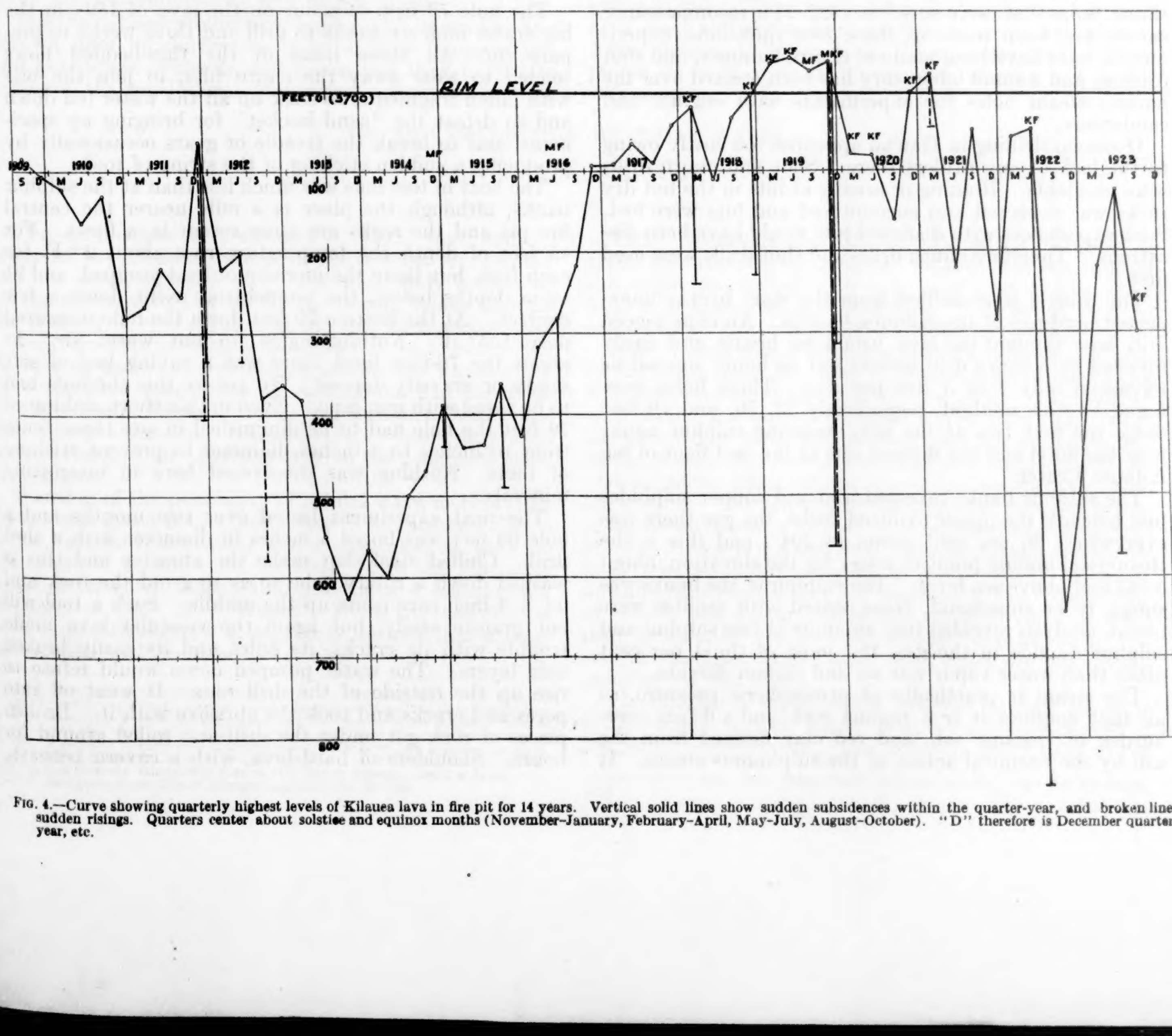

FIG. 4.—Curve showing quarterly highest levels of Kilauea lava in fire pit for 14 years. Vertical solid lines show sudden subsidences within the quarter-year, and broken lines sudden risings. Quarters center about solstice and equinox months (November–January, February–April, May–July, August–October). "D" therefore is December quarter-year, etc.

THE BORINGS AT KILAUEA VOLCANO

By T. A. JAGGAR, Volcanologist

[Volcano House, Hawaii, January, 1924]

The scientific value of making borings on a live volcano has been discussed among geologists for many years. It has been discussed by business men, also, in Hawaii, with the notion that endless power resides in that boiling lava. The use of steam for generating electricity at Larderello in Italy has been much quoted as comparable to what should be done in Hawaii. The late Mr. John Brooks Henderson, of Washington, D. C., in 1920 furnished some money to start boring experiments at Kilauea and other money was raised by the writer through the Hawaiian Volcano Research Association to supplement the Henderson gift. Some of this was furnished by the Whitney endowment of the Massachusetts Institute of Technology.

The plan discussed was referred to Dr. H. S. Washington, of the Geophysical Laboratory of the Carnegie Institution, to several experienced engineers and firms making boring apparatus and to practical drillers. The big problems confronting the work were the lack of natural water, the effects of the hot porous hard lava on drill tools, and the lack of roads for transporting machinery across the rough lava fields.

The information expected from borings is fourfold at a lava crater: First. How does the temperature increase as one goes down? Second. How does the undeground temperature change across country for the same depth? Third. What are the mineral changes underground? Fourth. What are the gas changes undeground? From the six holes that were bored in 1922–23 a reconnaissance survey has been made of these four questions, experimental tests have been made of churn, hammer, and shot drilling, and a small laboratory has been erected over the hottest steam holes for experiments with engines and condensers.

Diamond drilling in Hawaii appeared too costly owing to the lack of any drillers there. Shot and churn drills were available. Binding or seizing of bits in the hot dry rocks was expected and encountered and bits were lost. Such experiences with diamond bits would have been disastrous. Therefore churn drills and shot drills were used first.

The drillers were baffled from the start by the unexpected hardness of the Kilauea basalts. An experienced drill boss thought the lava would be brittle and easily invaded by a churn drill several feet an hour; instead he advanced only 2 or 3 feet per day. Three holes were bored by this method, respectively 23, 50, and 79 feet deep, the first two at the hot, steaming sulphur banks near the hotel and the deepest one at the east floor of big Kilauea Crater.

The sulphur banks revealed iron and copper sulphides just beneath the upper oxidized rocks, the gas there was everywhere 96 per cent steam at 204°, and this is the theoretical boiling point of water for the elevation, about 3,945 feet above sea level. The sulphur of the banks was shown to be superficial, veins coated with zeolites were found, analysis revealed tiny amounts of free sulphur and sulphur dioxide in the gas, but most of the 4 per cent other than water vapor was air and carbon dioxide.

The steam is practically at atmospheric pressure, as all that confines it is a porous rock and a 6-foot overburden of volcanic ash, and red clay derived from the ash by the chemical action of the sulphurous steam. It seems nearly certain from the boring samples that the steam comes from profound depths along vein cracks that here constitute a zone of fracture at the edge of an ancient part of the crateral lava fill. These cracks are deeper than other large chasms near by, to judge from their sulphurous emissions, or else the subterranean lava under them rises near to the surface, bringing up its heat and its dissolved sulphur gases.

The constant temperature for 50 feet of depth was striking, and the coincidence of this temperature with the boiling point for the elevation suggested the teakettle effect. That is, the rain water somewhere underground was boiling like a teakettle. There is plenty of rain, a hundred inches a year, more or less, at the observatory near by, but there are no springs, or brooks, or ponds, for the lava is so porous all the rain soaks down right away. This water may maintain a seepage which is brought to boiling at the hot lava level. But that level might be a thousand feet down or more, in which case the boiling temperature should be higher. Indeed the absence of springs on the active volcanoes everywhere except at sea level makes it probable the ground-water level under Kilauea is very low. If the borings could be pushed down a thousand feet at the sulphur banks some very interesting discoveries might be made. The 50-foot hole without any change of temperature merely whets the scientific appetite!

The hole 79 feet deep out on the lava of 1894 in the big crater took six weeks to drill and three weeks to prepare for. All these holes in the thin-bedded flows tended to wear away the churn bits, to jam the bits with fallen fragments, to soak up all the water fed down and so defeat the "sand bucket" for bringing up specimens, and to break the treadle or gears occasionally by producing a sudden sticking of the string of tools.

The heat in this hole was much less than at the sulphur banks, although the place is a mile nearer the central fire pit and the rocks are more recent lava flows. For 45 feet of depth the temperature rose about 2° F. for each foot, but there the increase of heat stopped, and at some depths below, the temperature went down a few degrees. At the bottom 79 feet down the hole measured only 155° F. Nothing came up but warm air. At about the 70-foot level there was a caving bed of soft sandy or gravelly deposit. To get by this the hole had to be cased with iron pipe. Even in this short sinking of 79 feet the hole had to be diminished in size three times from 10 inches to 4 inches diameter to prevent sticking of tools. Nothing was discovered here in interesting minerals.

The next experiment lasted over two months and a hole 60 feet was bored 5 inches in diameter with a shot drill. Chilled steel shot make the abrasive and this is washed down a rotary tube so as to grind the rock and let a 4-inch core come up the middle. Such a tool will cut granite easily, but again the vesicular lava made trouble with its cracks, its holes and its easily broken thin layers. The water pumped down would refuse to rise up the outside of the drill rods. It went off into pores and cracks and took the abrasive with it. Broken pieces of rock got under the drill and rolled around for hours. Shoulders of hard lava, with a cavern beneath,

would catch the top of the tool, bump it until the core had dropped down the hole, and delay progress lamentably.

This hole was in the observatory grounds among the warm vapor cracks of the upper edge of Kilauea Crater, not far from the sulphur banks. But it was not hot at all, only about 100° F. at the hottest, and the hottest place was only 20 feet down, while below it was cooler! Its minerals and its gases were lava and air. Its temperature changes were neither gradual nor consistent. Presumably it was cooled or warmed locally by inclined cracks bringing up air or vapor.

The rest of the boring was done with the shot drill at the sulphur banks, extending the 50-foot hole to 70 feet, losing two bits in its hot depths and sinking two more shallow holes on each side of it for tapping the steam zone. By casing the deeper hole with cement (for convenience of drilling) it was learned that less steam rises from below the 50-foot level than from the 15-foot level. Therefore the two side holes were lowered only 15 feet, and the battery of three holes was piped to the adjacent steam laboratory for physical and chemical tests dealing with power, condensation of water, and corrosive action of this vapor on metals. No new temperature data were revealed by this last spell of drilling at the sulphur banks. Throughout all the holes at this place the temperature was 204° F.

The discovery that more steam lies just below the ash beds than at 70 feet down seems to imply that the steam-bearing veins outcrop on an inclined zone crossed by the drilling in the upper levels of the wells. At the lower levels the drilling had penetrated the footwall, and here there was less sulphide as well as less steam.

Thus have these preliminary borings at Kilauea Volcano thrown light on differences of subsurface temperatures and subsurface minerals and gases, but they have also explored the possibilities of method. Hammer drilling with compressed air or electricity for holes not more than 25 feet deep at many places would be illuminating. Air hammers cut the lava rapidly in 3-inch holes at Hilo quarries and use very little water. They bore 25 feet in two hours easily. It is necessary to have large and powerful compressors and air tanks. It remains to be proved whether any system of hammer drilling can be made sufficiently portable to run a line of holes across Kilauea Crater in several directions for measuring subsurface temperatures under uniform conditions.

In the work on Kilauea floor much was learned about hauling water and drill rigs over lava topography without roads. A Ford automobile was rigged with six gears and double tires on rear wheels. This did most of the work. Other kinds of tractors and trucks proved less serviceable. A way was searched out, marked with stones, beaten down and filled slightly, and then the rig was divided into appropriate loads and hauled to its destination.

As to deep drilling, the diamond is probably the proper tool and the center of the greater crater would be the ideal place for trying it. It would be necessary to accumulate water in large tanks in advance and to be prepared for losses of valuable bits. Fifty thousand dollars might bore a hole there from one to two thousand feet deep and reveal intensely interesting facts bearing on gases, minerals, and temperatures.

All the holes bored have their openings cased and covered, and these become valuable assets of the volcano observatory for furture temperature measurements and physical experiments. Nothing sensational has yet been learned bearing on the utilization of Kilauea power. There is available power at the sulphur banks in small amount, but no superheated steam at high pressure such as is used at Larderello or such as may be available in Napa Springs, Calif., or in the Yellowstone Park. These places of high pressure steam are usually *not* active volcanoes.

ON THE PREDICTION OF TIDAL WAVES [1]

By R. H. FINCH, Meteorologist

[Volcano House, Hawaii, August 9, 1923]

The earthquake of February 3, 1923, that had its origin off the Aleutian Islands or the coast of Kamchatka and the resulting tidal wave that noticeably influenced all the northern half of the Pacific Ocean, brings to mind the possibility of accurately predicting such waves.

Tidal-wave predicting is not new; in fact, before the days of instrumental seismology seismic sea waves often gave the first notice that an earthquake had occurred. In 1904, Baron Kikuchi [2] made the statement that "further observations [on tsunami-tidal waves] may lead to important results, perhaps even to the prognostication of tsunami."

Warning of the possibility of a tidal wave in Hawaiian waters was given about four hours in advance on Feb. 3 at the Volcano Observatory and at Kealakakua, both on the island of Hawaii. At the latter place the Hawaiian Volcano Research Association maintains a seismograph in charge of Capt. R. V. Woods. When the instruments were inspected about 8 a. m. it was noticed that a large earthquake had occurred.

There is considerable discrepancy in the distances as given by several seismographic stations but the time at the origin was probably close to 16h. 02m. G. M. T. or 5:32 a. m. Hawaiian standard time. The velocity of the sea waves to Hilo was about 7.5 miles per minute.

It is obvious that a displacement of a considerable area on the ocean floor, the cause of practically all tidal waves, will produce several waves of different size. The velocity with which the large and small waves travel even over the same ocean stretch is different and the total duration of the seismic sea waves produced is a variable and depends, among other things, largely on the distance from the source. The velocity of the large waves is a function of the ocean depth. As the depth between any two points in most oceans is not uniform, and also islands and shoals intervene, no simple equation between velocity, gravity, and depth is satisfactory for computing the transit time of seismic sea waves, rather the problem resolves itself into integrating for several average depths. The observed velocities range from 3 to 8 miles per minute depending on the depth.[3]

The number of earthquakes followed by tidal waves is rather small, though larger than would be expected if judged by press reports. Undoubtedly many tidal waves

[1] Tidal waves as here considered as the popular term for what might more properly be called seismic sea waves. Captain Woods immediately notified all interests along the coast on his side of the island to look out for a tidal wave. A few people at Volcano House and at Hilo were notified that there was a possibility of a tidal wave about 12 o'clock. The wave reached Hilo at approximately 12:30 p. m. and Haleiwa, on northwestern Oahu, about 225 miles northwest, at 12:02 p. m. At Hilo there was one fatality. Considerable property damage was done at Hilo and at Kahului, island of Maui.

[2] *Pub. Earthquake Inves. Comm. Foreign Languages*, No. 19, 1904.

[3] *Jour. Col. Sci. Imp. Univ. Tokyo*, vol. 24, 1908; also Davison, *Manual of Seismology* p. 98.

are so small when they reach inhabited coasts that they can be detected only by tide-gages. The height of the waves vary from 84 feet, actual measurement (210 feet reported in another case) to less than an inch. The period of the waves as well as their height depends on the size and shape of the bay affected as long ago pointed out by Omori. Where deep water occurs right up to the shore line the waves have but little effect and may even escape detection while the same wave may be destructive on an adjacent coast that is bounded by shallow water. It has been found that for several Japanese bays and some others that the periods of the waves are constant for each bay whatever the source and are the fundamental periods of the bay.[3] The periods as observed vary from 5 to 30 or more minutes. The length of the waves sometimes reach 200 miles.

During the eleven years that seismographs have been in operation at the Volcano Observatory several earthquakes that were followed by tidal waves have been recorded. The one on September 7, 1918, in the Kamchatka region, 3,200 miles away, caused a tidal wave that did some minor damage in Hilo. The computed velocity of this wave was nearly 8 miles per minute. Another on April 9, 1919, the origin of which appears to have been southwest of Hawaii, affected a large part of the Pacific Ocean. There is considerable shallow water between Hawaii and the origin, and the velocity of the sea wave to Honolulu was 4.7 miles per minute while the velocity to San Francisco was 5.9 miles per minute. The mean depth of the ocean to the last-named port is much greater than to Hawaii. The small tidal wave that followed the Chilean earthquake of November 11, 1922, was predicted by T. A. Jaggar, jr., nearly 10 hours in advance. The velocity of the waves to Hilo in this case was 7.5 miles per minute. On April 13, 1923, a very small record of an earthquake was obtained about 5:17 a. m. and at 12:40 p. m. a small tidal wave occurred at Hilo. The record was too feeble to determine the distance, but from the time of the tidal wave the order of magnitude of the distance was computed to be near 3,000 miles. Later reports from other stations make the origin near Kamchatka, about 3,200 miles away.

It is usually impossible to make positive predictions of tidal waves from the records from one station, for even if the distance and general direction is known the distribution of land is such that there is nearly always a doubt as to whether the break occurred on land or under the ocean. As the seismographs are inspected rather infrequently a quake might be recorded and the tidal wave occur before it was ascertained that there had been a quake unless a device is arranged whereby a bell is made to ring whenever a quake is being recorded.

The fact that the transit time of the first preliminary waves through the earth in minutes and seconds is very nearly equal to the transit time of the seismic sea waves in hours and minutes affords a quick means of predicting the approximate time of arrival of the waves. A table is on file at this station showing the distance to most of the earthquake regions in the Pacific and the transit time of the sea waves from each region. The times were obtained either from known quakes that caused tidal waves or computed from the above rule.

[3] *Jour. Col. Sci. Imp. Univ. Tokyo*, vol. 24, 1908; also Davison, *Manual of Seismology*, p. 98.

C. E. P. BROOKS ON VARIATIONS IN THE LEVEL OF THE CENTRAL AFRICAN LAKES, VICTORIA AND ALBERT[1]

By ALFRED J. HENRY

[Weather Bureau, Washington, March 16, 1924]

The opening paragraph of this memoir contains the key to the discussion, viz, the remarkable way that the level of these lakes changes in sympathy with changes in the spottedness of the sun.

The evidence is presented both graphically by means of curves and also by the statistical method using the method of correlation coefficients, both of which seem to fully support the thesis.

Lake Victoria is situated between the meridians of 31° 40′ and 35° 00′ east of Greenwich and 0° 20′ north and 3° 00′ south latitude. The Equator passes over the northern part of the lake. Lake Albert is situated about 150 miles northwest of Victoria and is much smaller. The area of Victoria is 26,000 square miles; soundings made within 10 to 12 miles of shore give depths varying from 50 to 200 feet. In the bays and creeks the water is shallow; little is known of the depths in mid lake.

As one might expect, the numerical data utilized are neither plentiful nor of high accuracy. The precipitation data are derived from 10 stations scattered along the shore of the lake and elsewhere in Uganda. The early part of the record consists of a smaller number of rainfall records and is consequently less reliable.

The determination of the lake level rests upon daily gagings made at the eastern extremity of Kavirondo gulf, a deep indentation of the northeastern shore. The author gives only the single highest and lowest of these readings for each month. I have calculated therefrom the mean monthly lake level by the formula $\frac{\text{max.} + \text{min.}}{2}$ and present the monthly values in Table 1.

[1] Geographical Memoirs No. 20, Air Ministry, Meteorological Office, London, 1923.

TABLE 1.—*Mean monthly level, Lake Victoria (in inches and tenths)*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1896	26.0	23.0	22.5	22.0	23.0	22.0	19.5	18.5	14.5	11.0	15.5	17.5	19.6
1897	17.5	18.5	19.5	22.5	22.0	24.5	24.0	-----	-----	-----	-----	-----	-----
1898	-----	-----	-----	-----	25.0	22.0	23.0	22.0	22.5	22.0	22.0	22.5	-----
1899	20.0	18.5	18.0	18.0	21.5	22.0	15.5	5.5	4.5	−1.0	−1.5	2.0	3.6
1900	1.5	0.0	0.5	1.0	5.0	3.5	−1.5	−8.0	−2.0	−8.5	−13.0	−5.5	−1.8
1901	−4.0	−4.5	−2.5	11.5	20.0	18.5	11.0	4.0	−1.0	−3.5	−4.5	−7.5	3.1
1902	−10.0	−10.5	−10.5	−11.0	−6.0	−8.5	11.5	−10.5	−13.5	−11.0	−10.0	−3.5	−9.7
1903	−1.5	0.5	4.5	4.0	8.5	20.0	20.5	19.5	18.5	20.5	19.5	21.0	12.9
1904	16.0	19.5	18.0	22.0	27.5	21.5	19.5	22.0	10.5	12.5	12.5	15.0	18.0
1905	16.5	19.5	19.5	19.0	20.0	19.0	15.0	13.0	7.5	8.5	8.5	14.0	15.0
1906	15.0	16.5	21.5	35.0	41.0	41.5	27.0	35.5	32.5	25.5	27.0	26.5	28.7
1907	25.0	24.0	20.5	22.0	29.0	29.0	25.0	20.5	14.5	14.5	13.0	13.5	20.9
1908	12.5	9.5	10.0	8.5	12.0	12.0	11.5	10.5	8.5	8.5	10.5	10.0	10.3
1909	10.0	11.0	12.5	11.0	13.5	11.5	10.0	4.0	4.0	4.5	−1.5	0.5	7.6
1910	0.5	−2.0	−1.0	1.5	11.0	5.5	2.0	1.5	0.5	−3.5	−4.5	0.0	1.0
1911	−5.0	−8.5	−10.0	−5.5	0.0	2.0	−2.5	−6.0	−9.5	−13.0	−15.5	−14.5	−7.3
1912	−14.5	−11.0	−14.5	−11.5	−4.0	−4.0	−8.0	−10.0	−10.5	−13.5	−13.0	−12.0	−10.5
1913	−12.5	−9.0	−6.5	−6.5	4.0	8.0	7.5	0.5	−3.0	−6.0	−4.0	−4.0	−2.6
1914	−7.5	−6.5	−5.0	−2.0	1.5	2.0	0.0	−0.5	−2.0	−4.0	0.0	1.5	−1.9
1915	0.0	−2.5	3.0	4.5	6.5	11.5	13.0	2.5	1.5	1.5	2.0	4.5	4.0
1916	6.0	9.5	8.0	13.0	17.5	23.5	20.5	16.5	16.5	18.5	17.5	16.0	15.3
1917	20.0	23.0	23.0	30.5	40.5	43.5	38.5	36.0	37.0	39.5	43.5	40.5	34.6
1918	40.5	36.5	33.0	32.0	35.0	33.0	28.5	22.5	20.0	17.0	14.5	15.5	27.3
1919	9.0	−2.0	−0.5	3.0	14.5	18.5	13.5	7.0	8.5	6.5	6.0	7.0	7.6
1920	6.5	3.5	0.5	6.5	10.0	10.5	4.5	1.5	−0.5	−2.5	−5.0	−4.0	2.6
1921	0.5	1.5	0.0	−1.0	−1.5	−1.5	−2.5	−6.5	−9.0	−10.5	−11.5	−13.0	−4.6
1922	−16.0	−14.0	−18.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

The gage readings are fairly consistent among themselves except in the single instance of July, 1906, the minimum reading for that month appearing to be at least 10 inches too low. The monthly mean for June of the same year is 41.5 inches, July 27 inches, and August 35.5 inches. Neglecting the rain which fell upon the surface of the lake, 2.30 inches, there remains a shrinkage of 14.5 inches in level over an area of 26.000 square miles in a single month. This amount is so greatly in excess of any recorded measurements of evaporation that it seems to be quite improbable. If the reading was as reported it must have been due to some unusual local condition that did not affect the level of the lake generally.

The rainfall departures from the normal are presented in Table 2 below, together with the monthly means or normals in the bottom line.

TABLE 2.—*Average rainfall over Uganda (departures from monthly and annual normals).*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1895	−0.26	−0.29	+0.76	+7.09	+5.50	−1.95	−0.55	−0.22	−0.25	−0.13	+4.74	+0.32	+14.76
1896	+0.12	−2.27	−0.25	−1.54	−2.93	−0.93	−1.09	+1.21	−1.49	0.00	+5.55	−0.38	− 4.60
1897	−0.58	+0.28	−0.67	+0.52	+0.34	+0.84	+0.24	+3.34	+4.22	+2.77	+0.18	−1.28	+10.20
1898	+1.00	−1.57	−1.08	−2.24	−3.97	+2.11	+0.07	+0.16	+0.70	−0.06	+0.36	−1.08	− 5.60
1899	−2.00	−0.12	−2.55	−0.52	+0.07	−2.35	−1.77	−2.35	−2.09	−0.94	−0.95	−0.13	−15.70
1900	+0.92	+2.69	+1.30	−0.95	−3.45	−1.21	−1.76	+0.27	−0.42	−1.07	+2.44	+5.05	+ 3.81
1901	−0.69	+2.57	+0.88	+0.33	−0.74	−2.06	−0.44	−2.02	−1.65	−1.25	−1.17	−1.58	− 7.82
1902	−0.97	+0.02	−1.03	−1.21	+0.71	−1.11	−2.18	+1.52	−1.32	+0.80	+1.18	+0.36	− 3.23
1903	+2.27	−1.50	−0.11	+0.60	−0.59	+4.30	+0.65	−1.46	+1.72	+0.98	−2.64	−0.40	+ 3.82
1904	+0.84	+0.49	+1.89	−1.33	+0.61	−0.41	−0.89	+1.05	+0.36	+1.30	+2.29	+2.52	+ 8.72
1905	+0.92	−1.08	+3.80	−2.36	−0.22	−0.84	+0.79	+0.03	+1.21	+2.41	+3.04	+2.55	+10.25
1906	−0.95	+2.55	+2.62	+2.03	−0.58	+1.55	−0.13	+0.99	−0.03	+0.96	−2.44	−0.88	+ 5.69
1907	+0.07	+1.27	−3.05	+3.87	+3.05	−0.15	−0.07	−0.97	−0.15	+0.87	+1.96	+0.36	+ 7.06
1908	−1.12	+0.12	−2.39	+1.00	+1.52	+0.51	−0.08	+0.93	−1.86	+0.30	−0.66	−0.22	− 1.95
1909	+0.39	−1.77	+1.10	+3.32	−1.56	−1.17	−0.16	+1.82	+1.75	−0.58	−1.13	+4.06	+ 6.07
1910	+1.40	−0.31	+0.95	+0.87	+2.00	−0.33	+1.83	+0.59	−0.82	+0.89	−0.26	+0.44	+ 7.25
1911	−0.24	−1.82	+1.95	+0.04	+1.54	−0.91	−0.88	−0.81	−2.02	−0.40	−3.19	−1.79	− 8.53
1912	+0.69	+0.19	+0.27	+1.42	−0.20	+0.41	+0.27	+1.19	+0.49	−0.90	−0.06	+0.56	+ 4.33
1913	−0.82	+0.64	−0.13	−0.11	+0.02	−0.51	−0.28	−2.29	−1.97	−0.51	−1.87	−1.49	− 9.32
1914	−0.29	−0.63	−0.14	−2.57	−0.59	+0.66	+0.78	+0.11	+1.50	−0.45	+1.60	−1.34	− 1.36
1915	−0.68	−0.88	+0.94	−1.59	−0.52	+0.60	−0.80	−1.91	+0.57	−0.71	−0.73	+0.85	− 4.86
1916	−0.55	+1.13	−0.57	−0.06	−0.82	+0.68	−0.63	0.00	+2.07	−0.59	−1.16	+0.06	− 0.44
1917	+0.65	+1.71	−2.88	+1.98	+0.58	+0.30	−1.42	+0.79	+0.43	+0.64	−2.62	−2.05	− 1.89
1918	−0.30	−1.77	−1.72	−0.63	−0.37	−0.59	−0.51	−1.03	−0.89	−1.55	−1.79	−1.03	−12.18
1919	−1.04	+2.54	+0.45	−2.22	−0.55	−0.97	−1.63	−0.53	−0.89	−0.82	−0.12	−0.86	− 6.64
1920	−0.52	−1.72	+0.22	−0.68	+0.26	+0.58	+0.24	−1.16	−1.41	−0.34	+0.04	−0.07	− 4.56
1921	−0.65	−0.73	−2.44	−2.93	−0.59	−0.25	−1.85	−0.26	−0.21	−0.46	0.00	−0.32	−10.69
1922	−0.98	−0.07	−2.25										
Mean	2.17	3.06	4.60	7.35	5.82	3.58	2.48	3.80	4.60	4.76	5.16	3.33	50.71

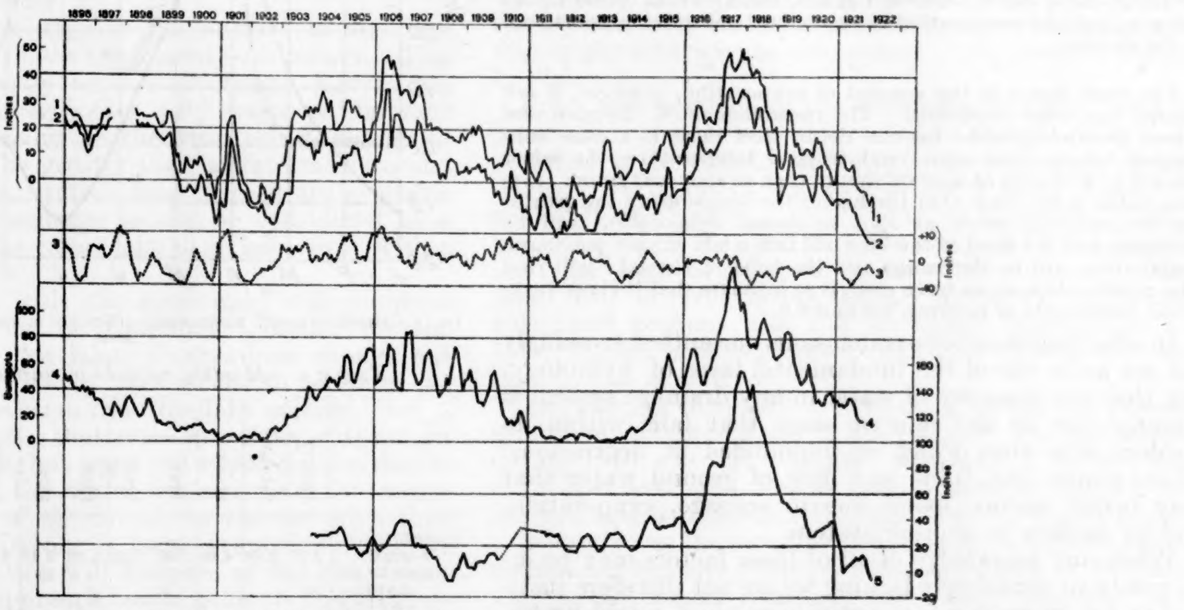

FIG. 1.—Curves 1 and 2, monthly maximum and minimum lake levels in inches above or below zero level. Curve 3 rainfall in Uganda, deviations from normal summed in overlapping periods of six months. Curve 4, monthly sun-spot numbers. Curve 5, mean level of Lake Albert in inches above zero level

The climate of the two lake basins considered is tropical with the usual two rainy seasons corresponding approximately with the times of vernal and autumnal equinoxes; the autumnal rainy season being delayed somewhat, the maximum monthly amount falling in November. It is to be remembered, however, that some rain falls in each month of the year and that the minimum monthly amount is 2.17 inches (normal for January).

This figure shows the author's graphical method of showing the parallel values of lake level, rainfall, and sun spots. In making the rainfall curve the, sums of the monthly deviations in overlapping periods of six months have been used. The sun-spot curve has been produced through the use of Wolfer's relative numbers as published in Meteorologische Zeitschrift, smoothed by taking the mean of each three successive months, allocated to the middle one.

In addition to direct correlations partial correlation coefficients were calculated showing the relation between lake levels and rainfall, the sun spots being constant, and between lake levels and sun spots, rainfall being constant. In Table 3 below the suffix "1" indicates lake level, "2" rainfall, and "3" sun spots. The usual notation is employed, 12.3 meaning correlation coefficient between lake level and rainfall corrected for sun spots and so on. In the third line, coefficients deduced from annual means have been added for comparison.

TABLE 3.—*Correlation coefficients between lake levels, rainfall, and sun spots*

	r_{12}	r_{13}	r_{23}	$r_{12.3}$	$r_{13.2}$
1899–1921	+0.26	+0.74	+0.12	+0.25	+0.72
1902–1921	+.29	+.81	+.08	+.39	+.82
1902–1921	+.[illegible]	+.87	+.12	+.59	+.90

Annual figures.

From the foregoing-named data the author concludes as follows:

From Table 5 (Table 3 of this abstract) it appears that while the level of Lake Victoria depends to some extent upon the rainfall, the relation to sun-spot numbers is much more close, the corrected coefficient reaching +0.82 for the period 1902–1921, even when monthly figures are considered, in spite of the fact that no lag is allowed for, while the annual means which to some extent compensate for the lag and also tend to smooth out irregularities, give a corrected coefficient as high as +0.90. These are remarkable figures, and indicate a very close connection between the lake levels and the radiation from the sun. Such a connection can only be through evaporation (p. 342).

And again: (p. 343):

After allowing for these factors [rainfall and run-off] enough agreement remains to show that evaporation is responsible for by far the greatest loss of water in Uganda, and also that (other things being equal) the evaporation is nearly but not quite proportional to the rainfall.

* * * * *

The chief factor in the amount of evaporation, however, is not rainfall but solar conditions. The researches of W. Köppen and others have established beyond doubt that there is a close connection between sun spots and tropical temperature, the latter being 1.1° F. higher at spot minimum than at spot maximum. It is reasonable to conclude that the higher the temperature the greater the evaporation; hence at spot minimum evaporation will be increased and the level of the lake will fall, while at spot maximum evaporation will be decreased and the level of the lake will rise. The relationship, as we have seen, is so intimate that it gives correlation coefficients of between 0.8 and 0.9.

In affirming the above conclusions our author seemingly has set aside one of the fundamental laws of hydrology, viz, that the quantity of water in any drainage system is directly due to the rain or snow that falls within its borders plus that which is impounded in depressions, lakes, ponds, etc., plus any flow of ground water that may occur; minus, losses due to seepage, evaporation, and by outflow to another system.

While our knowledge of all of these factors may be incomplete, or completely lacking we are not therefore justified in assuming as a fact, something which might probably be true, but has not as yet been proved to be true.

It is perhaps unfortunate that the author did not have more extended data on the synchronous variations of sun spots and lake levels. The period used, 1896–1922, contains but 2 epochs of maximum sun spots and say 3 epochs of minimum spots, although the precise epoch of 1923 has not yet been fixed. In all he had but 5 events whereas he should have had at least 6 times that number.

A simple comparison of the two variables, sun spots and lake levels will now be made.

Sun spot maxima, 2 epochs, 1906 and 1917.—High lake levels prevailed in both years but the high water in the first named was clearly due to increased rainfall as shown in Table 2.

Sun spot minima, 2 epochs, 1901 and 1913.—The mean lake level in 1901 was 3.1 inches; it should be classed as a year of moderately low water. The water level in 1913 was −2.6 inches, a year of low water. Low lake levels also prevailed in 1902, −9.7; 1910, 0.9; 1911, −7.3; 1912, −10.3; 1914, −1.9; 1921, −4.6 inches.

It is quite apparent from the above that low lake levels for the period, 1896–1922, tend to group themselves around years of few sun spots, although not necessarily around the epoch of minimum spots of each cycle. We will return to this subject later.

It seems to be worth while to examine in greater detail relation between rainfall and lake levels. Using the monthly normals as found in Table 4, I have plotted the month-to-month accumulated differences and present the curves so formed in Figure 2.

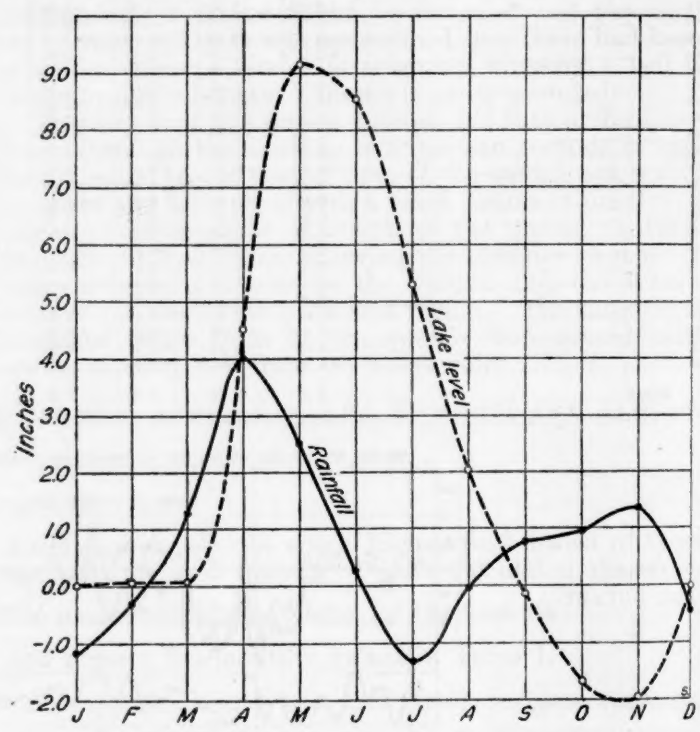

FIG. 2.—Month-to-month accumulated differences of normal rainfall and normal lake level

TABLE 4.—*Monthly normals of rainfall and lake levels*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
Rainfall:													
Normal	2.17	3.06	4.60	7.35	5.82	3.58	2.48	3.80	4.60	4.76	5.16	3.33	50.71
Sum for six months ending with the named month	23.82	23.08	23.08	25.67	26.33	26.58	26.89	27.63	27.63	25.04	24.38	24.13	25.35
Height[1] of Lake Victoria:													
Normal monthly, maximum	12.7	13.2	13.2	17.2	21.9	21.2	18.0	14.7	12.4	11.0	10.7	12.7	14.9
Normal monthly, minimum	0.5	−0.6	−0.5	2.8	8.7	10.4	6.5	3.4	1.3	0.1	−0.5	0.4	2.7
One-half (max. +min.)	6.6	6.3	6.3	10.0	15.3	15.8	12.3	9.1	6.9	5.5	5.1	6.5	8.8
Height[2] of Lake Albert (mean monthly)	44.1	39.9	35.0	33.6	33.4	34.5	34.9	36.1	39.7	42.7	46.0	46.0	39.4

[1] In inches above the zero level of 3,276.15 feet above m. s. l.
[2] In inches above the zero level of 2,028.1 feet above m. s. l

From the curves of the above figure it will be seen that there is close agreement between rainfall and lake level and that there is very little lag between them. The rainfall increases from January to April; the lake rises from March to May, cresting just one month after the rain maximum. The rainfall begins to diminish in May and likewise the level of the lake begins to descend in congruence therewith. The decrease of rainfall from the April maximum of 7.35 inches to the July minimum of 2.48 inches is, of course, 4.87 inches.

The months of greatest evaporation are July, August, and September. The fall in the level of the lake which is very pronounced in June and July is apparently checked in the last-named month and while it continues to fall until November, in spite of the second rainy season, a rise sets in, in that month, that culminates in December, when it has reached the secondary maximum of the year. This secondary maximum is considerably less than the primary by reason of the great evaporation loss during the months, July to October, and the diminished rainfall of the autumnal as compared with vernal rainy season.

The curves of Figure 2 show the following relation, viz, that with a rising lake and small evaporation, as must naturally be the case in the rainy season, the ratio of normal precipitation to normal lake level is about as 1 to 2; thus the accumulated increase in normal precipitation, February to April, is 4.29 inches (from Table 4), the normal rise in lake level March to May, allowing a month's lag is 8.7 inches. With falling lake and increasing evaporation as the dry season approaches, the ratio diminishes slightly, thus decrease in normal precipitation April to July, 4.87 inches; decrease in lake level May to August 7.2 inches. The decrease in the ratio obviously is due to the greater evaporation in the one season as compared with the other.

Throughout this discussion the outflow of the lake over Ripon Falls has been considered as constant. This is not, however, strictly true, as Professor Marvin has orally pointed out to the writer. By reason of high lake levels at certain seasons of the year the discharge at those seasons must be greater than at intermediate and low stages. No quantitative data thereon are available but the increased discharge should be considered as a factor in reducing the ratio, rainfall to lake level, with a falling lake.

It is a pity that with the apparently well-equipped meteorological station of Entebbe, Uganda, on the northwest shore of the lake, observations should not have been made that would have served to compute the possibilities of evaporation from the lake surface.

It is known of course, that evaporation depends not on the relative humidity, but upon the vapor tension due to the temperature of the water surface, and the vapor tension of the layer of air directly in contact with that surface. If this difference is large evaporation will be rapid, while evaporation will decrease as the two values of vapor tension approach each other. The records of the Entebbe station contain readings of the wet and dry bulb thermometers made three times daily but no records of water temperatures.

We may get some idea of the possibilities of evaporation by considering the effect of a definite change in the air temperature of the layer in immediate contact with the lake surface. The mean maximum air temperature in the thermometer shelter at Entebbe for June, July, August, and September is 77.5 + 77.0 + 77.3 + 79.0 ÷ by 4 or 77.7 F. For the sake of argument let us assume a drop in temperature for these four months to 76 F. or 1.7 less than the 10-year mean.

The maximum pressure of aqueous vapor over water at—

	Inch
Temperature 77.7 F. is	0.9581
Temperature 76 F. it is	0.9056
Diff	0.0525

With no change in water temperature the evaporation would be diminished almost 5 per cent by a drop in air temperature of 1.7 F. Since the assumed drop in temperature in the above example is greater than that postulated by the author it is difficult to see on what grounds a large evaporation is to be expected at times of spot maximum or minimum.

Curiously enough the author seems not to have gone to the trouble of ascertaining whether or not the air temperature at Entebbe, the only meteorological station on the lake, had varied in consonance with the sunspot theory. I have computed the 10-year mean of the annual temperature maximum and minimum, respectively, for Entebbe. The means are as follows: Mean maximum 78.9 F.; mean minimum 62.8 F. For 1917 the year of spot maximum the temperature at Entebbe was *above* the 10-year mean as follows: Mean maximum +0.8 F., mean minimum +0.4 or directly the opposite of that called for by theory. The temperature in the spot minimum year of 1913 was also above the 10-year mean.

We have not yet touched upon by far the most interesting problem presented in the memoir, viz, whence came the water that filled the lake to overflowing in 1917? We feel reasonably sure that it did not come as a result of diminished evaporation in the drainage basin of the lake, although a small portion may have had its origin in that manner. I have plotted the course of the lake for the three years, 1916–1918 in order to bring out some points that might otherwise be overlooked. The result is shown in Figure 3.

From this point on in the discussion the lake itself is considered as a better index of the precipitation that occurred in the drainage basin than the rain gages themselves. During 1916 the level of the lake increased 10 inches, from 6 inches in January to 16 inches in December, in spite of the fact that the rainfall deviations for the year were negative by nearly half an inch. The small drop in level during the dry months of June and July, and perhaps also the decreased evaporation of July, August, and September may partially account for the increase in level.

The average shrinkage in lake level for the dry season computed for 25 seasons is 8.8 inches. The shrinkage during 1916 was but 7 inches, or nearly 2 inches less than the average. Possibly this amount should be charged against diminished evaporation. I do not know.

Not only was the high level attained in December, 1916, maintained but an additional increase in level of 4 inches was gained during January, 1917, and thus the lake *inherited from 1916* a gain of 14 inches of water spread over 26,000 square miles.

The deviation of the 1916 rainfall from the normal, see Table 2, was −0.44 inch, small and negative to be sure, but this is a case where the figures do not tell all of the story. The detailed records of the Entebbe station show that for March, 1916, there were 11 rainy days, April, 15 rainy days, May, 11 rainy days, June, 15 rainy days, a total of 52 of which 32 were consecutive, as follows: March 7, April 9, May 4, and June, 12. This means that the sequence in which the rain falls is of more importance than the actual

amounts. In June 4.81 inches fell on consecutive dates from the 18th until the 30th; the greatest amount in any 24 hours during this period was but 1.10 inch and the least 0.06 inch, but the effect is clearly apparent in Figure 3 and in the numerical values of Table 1. Evaporation is not only greatly reduced by continuous cloudy rainy weather, but the run-off is much greater because the vegetative cover of the basin becomes thoroughly wetted and sheds water so much the quicker and with less loss from interception and absorption.

The rainfall record for 1917 is much similar, the annual deviation from normal being −1.89 inches. Here again annual figures are not significant; one should consult the monthly deviations as shown in Table 2. These show that rainfall was decidedly below normal in March, moderately below in July, and decidedly below in both November and December. The detailed record of rainfall made at Entebbe shows that March had but 3 rainy days, April had 23, of which 18 *were consecutive*; May had 19, 13 *consecutive*.

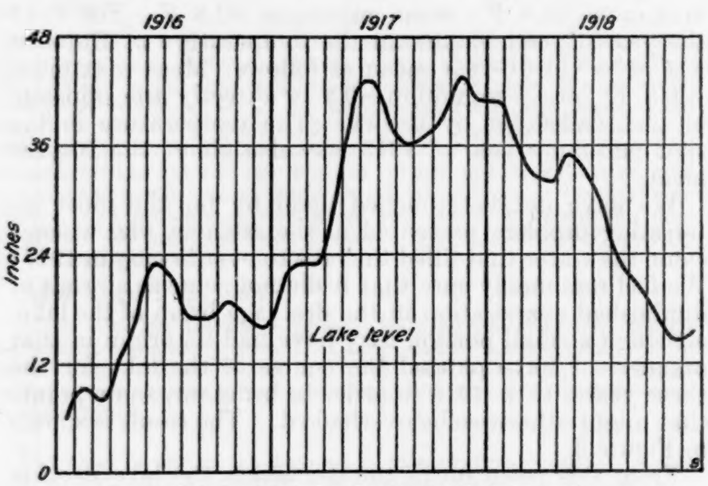

FIG. 3.—Lake level, in inches, for 1916–1918 (Lake Victoria)

June had 7, scattered throughout the month, and July had but 0.02 inch for the entire month; August 15 rainy days, 5 *consecutive;* September, 12, 6 *consecutive;* October, 10, 5 *consecutive;* November and December had few rainy days and they were scattered throughout the month.

By following the curve of Figure 3 it will be seen that the lake rose practically uninterruptedly from January to June in perfect congruence with the rainfall. The lack of rain in July, only 0.02 inch is manifest in the drop in the curve for July and August. More rain, favorably distributed sent the lake up to a second maximum in November equal to the first maximum in June.

A period of deficient rainfall set in in November, 1917, continuing uninterruptedly for 14 months, then followed 2 months of normal rains and again a deficient period, this time lasting without a break for 11 months. The lake level was, of course, falling during these periods of deficient rains and reached in March, 1922, the lowest point ever recorded, viz, 18.5 inches below its normal level. The lake level will of course rise in response to a return of the rainfall to normal. The high water of 1917 might be explained in one or more ways as independent of the rainfall; first, the discharge over Ripon Falls might have been greatly retarded through channel obstructions during 1916 and 1917, or, second, prevailing southerly winds during these same years may have driven the water to the northern end of the lake—the neck of the bottle; but it is preferred to believe that the response of the lake to the natural rainfall and run-off has been such as might have been expected and that it is unnecessary to have recourse to changes in solar radiation to explain the variations in level as described.

Through the courtesy of Mr. R. Z. Kirkpatrick, chief hydrographer of the Panama Canal, the editor has been supplied with monthly values of observed evaporation from a 4-foot pan floating in Lake Gatun, Canal Zone, Panama, an artificial body of water formed by damming the Chagres River. The lake has an area of 164 square miles. The 11-year mean evaporation from this lake is roughly 60 inches, of which 44 per cent occurs during the dry season—January to April, inclusive, and the remaining 56 per cent occurs during the remaining months of the year. During the year of sun-spot minimum, 1913, evaporation from the lake was 108 per cent of the 11-year average; during the year of spot maximum, 1917, evaporation was 102 per cent of the average. The least evaporation was 87 per cent in 1921 and the greatest 109 per cent in 1918. There is here no suggestion of a sun-spot influence upon evaporation.

DISCUSSION BY C. E. P. BROOKS [2]

I am glad to see this review, although I do not entirely agree with your remarks.

The rainfall for Uganda employed in the original memoir were the best I could do at the time, and I was very glad to receive the more extensive figures given by Mr. Phillips, director, Cairo Hydrological Service (Nature, London, 113:440).

I have already had an opportunity of considering the effect of this modification, in an unpublished paper on the subject written at the request of the Uganda Literary and Scientific Society. I have unfortunately no spare copies of this paper, but may quote the following expression of my revised views:

> Since the level of the lake shows so close an agreement with the number of sun spots, the latter must have a dominating influence on one or both of the prime factors which influence the lake level, namely, rainfall and evaporation. A comparison of the average rainfall over the lake plateau, according to Mr. Phillips, with the sun spot numbers shows that the rainfall is generally high when sun spots are increasing and low when sun spots are decreasing. The change in the average sun spot number from one period of 12 months (July to June) to the succeeding 12 months shows a good agreement with the rainfall amounts * * * the correlation coefficient being +0.64, which indicates good but by no means remarkable agreement. The correlation coefficient between plateau rainfall and the change in the level of Lake Victoria is +0.91, indicating a very close agreement. Since the level of the lake depends on the rainfall and the rainfall depends on sun spots, it is evident that the level of the lake would show agreement with sun spots even if there were no other factor. To measure this agreement between lake level and sun spots through rainfall we multiply together the two correlation coefficients given above, i. e., $0.64 \times 0.91 = 0.58$, and this would be the correlation coefficient between lake level and the sun spots if no other factor than rainfall had to be taken into account. But the connection between lake level and sun spots is much closer than this; it gives a correlation coefficient of +0.87. Therefore some other factor in the lake le besides rainfall must be closely connected with sun spots, and * * * this factor must be evaporation.

[2] A copy of the foregoing having been furnished Doctor Brooks, he makes the following comment.

The agreement shown between the level not only of Lake Victoria but also of Lake Albert, and sun spots is so remarkably good that some intimate connection between the two variables must certainly be accepted, and this is the primary contention of the geophysical memoir referred to. By making use of the scattered reports of explorers previous to the installation of lake gages the lake-level curve can be carried back another eight years, and still it agrees with the sun-spot curve. Data for 1923 also support the agreement. Assuming a correlation of 0.8 for the 36 years 1888–1923 (between level of Lake Victoria and sun-spot numbers) the probable error works out as only $\pm .04$, and the coefficient is 20 times the probable error, which amounts almost to absolute certainty. To reduce the number of "occasions" to the six or seven maxima and minima amounts to assuming beforehand the truth of what you wish to disprove.

Working out the partial coefficients roughly we obtain lake level, sunspots, rainfall constant, $r = +0.92$; lake level, rainfall, sunspots constant, $r = +0.80$.

The first figure, 0.92 is practically the same as the crude coefficient between lake level and rainfall. This means that the level of the lake is determined almost entirely by two factors—rainfall, and sunspots—independently of their effect on rainfall. It is difficult to see any other means than evaporation through which the latter effect can operate. The run-off from the lake is so small (only about 6 per cent of the rainfall) that its variations can not appreciably affect these relationships.

The conclusion drawn from the data is therefore solely that the level of the lake is determined almost entirely by the balance between rainfall and evaporation. At first the chief effect was attributed to the latter, but Mr. Phillip's rainfall figures show rainfall to be of equal importance. Variations due to run-off, seepage, etc., are necessarily relatively unimportant, but they were so far from being ignored that on page 342 of the Memoir an attempt is made to calculate them. I therefore can not understand why I am accused of having "set aside one of the fundamental laws of hydrology * * *." Actually this elementary law was present in my mind throughout.

The use of temperatures at Entebbe for calculating evaporation would be irrelevant for two reasons. In the first place at stations on the edge of large bodies of water the sun-spot cycle of temperature variations is greatly modified by the incidence of lake or sea breezes, so that they are not a fair indication of the temperature of the mass of air blowing over the lake or sea, and, in the second place, with higher land temperatures some distance inland the wind movement would be greater and this would increase the evaporation disproportionately to the rise of temperature.

THE FREQUENCY OF WINDS OF DIFFERENT SPEEDS AT FLYING LEVELS BETWEEN NEW YORK AND CHICAGO: A FURTHER ANALYSIS OF THE RECORDS OF THE AIR MAIL SERVICE [1]

By WILLIS RAY GREGG, *Meteorologist*, and LIEUT. J. PARKER VAN ZANDT, United States Air Service

[Weather Bureau, April 4, 1924]

The effect of winds of different speeds on the performance of aircraft in regular service over a given route was examined in some detail by the authors in an earlier paper.[2] Because of the importance of this factor of wind frequency in aircraft operations it has been considered desirable to extend the analysis of the previous paper, particularly as regards the New York-Chicago route, in order to confirm or modify the earlier conclusions. The records of the air mail for the fiscal year 1923 have therefore been examined and combined with those for the fiscal year 1922, as previously determined, and the results of this more complete analysis are considered in the paragraphs which follow.

The flight data upon which the analysis is based were taken directly from the operating records of the air mail and cover the two-year period from June, 1921, to May, 1923, inclusive. Table 1 presents the number of flights by month and by season, the average speed maintained and the percentage of flights completed to the total number possible. This table corresponds to Tables 1 and 2 of the earlier report, to which reference should be made for a description of the route and of the general method of computation.

Table 2 presents the data corresponding to those of Tables 9 and 11 of the former report. Of particular interest is the last line which gives the wind factor as determined for the two consecutive years.

[1] Presented before American Meteorological Society at Washington, D. C., Apr. 30, 1924.

[2] The Wind Factor in Flight: An Analysis of one Year's Records of the Air Mail. MO. WEATHER REV., March, 1923, 51: 111-125.

TABLE 1.—*Flights made between New York and Cleveland and between Cleveland and Chicago, June, 1921, to May, 1923, inclusive*

	January	February	March	April	May	June	July	August	September	October	November	December	Spring	Summer	Autumn	Winter	Annual
	Number of days available, excluding Sundays and holidays																
	51	46	54	50	52	52	50	54	50	52	50	51	156	156	152	148	612
	Number																
New York-Cleveland	42	36	43	46	49	51	50	52	49	49	39	44	138	153	137	122	550
Cleveland-Chicago	46	39	50	48	51	52	50	54	50	52	45	46	149	156	147	131	583
Chicago-Cleveland	47	40	51	48	51	52	50	54	49	52	42	45	150	156	143	132	581
Cleveland-New York	40	38	44	45	49	51	50	52	49	50	39	47	138	153	138	125	554
	Percentage of possible																
New York-Cleveland	82.3	78.3	79.6	92.0	94.2	98.1	100.0	96.3	98.0	94.2	78.0	86.3	88.5	98.1	90.1	82.4	89.9
Cleveland-Chicago	90.2	84.8	92.6	96.0	98.1	100.0	100.0	100.0	100.0	100.0	90.0	90.2	95.5	100.0	96.7	88.5	95.3
Chicago-Cleveland	92.2	87.0	94.4	96.0	98.1	100.0	100.0	100.0	98.0	100.0	84.0	88.2	96.2	100.0	94.1	89.2	94.9
Cleveland-New York	78.4	82.6	81.5	90.0	94.2	98.1	100.0	96.3	98.0	96.2	78.0	92.2	88.5	98.1	90.8	84.5	90.5
	Average speed (m. p. h.)																
New York-Cleveland	90.4	87.8	89.3	89.6	96.6	89.6	88.4	90.0	89.6	88.6	86.1	89.7	91.8	89.3	88.1	89.3	89.6
Cleveland-Chicago	89.6	86.8	87.6	89.4	95.6	90.2	87.7	89.1	88.9	86.6	87.4	88.1	90.9	89.0	87.6	88.2	88.9
Chicago-Cleveland	107.1	106.5	105.0	104.5	94.9	93.3	96.6	95.5	98.7	104.5	106.2	105.7	101.5	95.1	103.1	106.4	101.5
Cleveland-New York	113.5	117.4	111.8	108.8	102.2	98.1	93.5	95.8	98.8	105.8	105.2	111.9	107.6	95.8	103.3	114.3	105.2

TABLE 2.—*Miscellaneous statistical data for flights between New York and Chicago, June, 1921, to May, 1923, inclusive*

	January	February	March	April	May	June	July	August	September	October	November	December	Spring	Summer	Autumn	Winter	Annual
Number of days, excluding Sundays and holidays	51	46	54	50	52	52	50	54	50	52	50	51	156	156	152	148	612
Number of flights each way	38	33	41	44	48	51	50	52	48	49	36	39	133	153	133	110	529
Percentage of possible	74.5	71.7	75.9	88.0	92.3	98.1	100.0	96.3	96.0	94.2	72.0	76.5	85.3	98.1	87.5	74.3	86.4
	New York-Chicago (m. p. h.)																
Average speed	89.0	88.0	90.0	89.6	96.4	89.8	88.0	89.4	89.2	87.8	87.0	88.6	92.0	89.1	88.0	88.5	89.4
Highest speed	122.2	117.6	113.4	125.6	113.4	104.1	106.1	106.2	108.1	119.0	109.7	110.8	125.6	106.2	119.0	122.2	125.6
Lowest speed	68.7	60.9	72.3	70.8	77.1	73.2	73.5	75.7	65.9	68.1	74.0	66.8	70.8	73.2	65.9	60.9	60.9
	Chicago-New York (m. p. h.)																
Average speed	110.4	112.8	108.0	106.8	98.8	96.0	94.8	95.6	98.8	105.4	105.4	110.6	104.5	95.5	103.2	111.1	103.6
Highest speed	139.7	154.0	137.5	130.5	129.4	120.5	111.3	112.4	128.3	145.0	136.3	145.8	137.5	120.5	145.0	154.0	154.0
Lowest speed	84.6	89.0	77.7	76.6	78.8	75.1	64.3	75.3	78.6	71.8	82.2	90.9	76.6	64.3	71.8	84.6	64.3
Normal cruising speed	99.7	100.4	99.0	98.2	97.6	92.9	91.4	92.5	94.0	96.6	96.2	99.6	98.2	92.3	95.6	99.8	96.5
Wind factor from data above given	10.7	12.4	9.0	8.6	1.2	3.1	3.4	3.1	4.8	8.8	9.2	11.0	6.2	3.2	7.6	11.3	7.1

TABLE 3.—*Miscellaneous statistical data for flights between New York and Chicago, June, 1922, to May, 1923, inclusive*

	January	February	March	April	May	June	July	August	September	October	November	December	Spring	Summer	Autumn	Winter	Annual
Number of days excluding Sundays and holidays	26	23	27	25	26	26	25	27	25	26	25	25	78	78	76	74	306
Number of flights each way	19	16	20	23	23	25	25	27	24	25	22	19	66	77	71	54	268
Percentage of possible	73.1	69.6	74.1	92.0	88.5	96.2	100.0	100.0	96.0	96.2	88.0	76.0	84.6	98.7	93.4	73.0	87.6
	New York-Chicago (m. p. h.)																
Average speed	89.1	89.6	89.6	91.7	99.4	91.1	91.8	93.2	92.9	91.4	88.1	90.3	93.6	92.0	90.8	89.7	91.5
Highest speed	122.2	117.6	113.4	125.6	113.4	100.3	106.1	106.2	108.1	109.8	109.7	110.8	125.6	106.2	109.8	122.2	125.6
Lowest speed	74.2	60.9	72.3	77.0	79.4	76.2	80.4	79.5	81.1	76.5	74.0	66.8	72.3	76.2	74.0	60.9	60.9
	Chicago-New York (m. p. h.)																
Average speed	113.7	117.7	116.1	109.4	99.7	99.9	98.7	97.1	98.1	106.8	110.3	115.8	108.4	98.6	105.1	115.7	106.9
Highest speed	139.7	154.0	137.5	129.6	129.4	120.5	110.3	112.4	112.1	145.0	136.3	145.8	137.5	120.5	145.0	154.0	154.0
Lowest speed	86.2	100.3	104.1	80.4	85.8	85.3	83.6	84.6	78.6	71.8	88.3	90.9	80.4	83.6	71.8	86.2	71.8
Normal cruising speed	101.4	103.6	102.8	100.6	99.6	95.5	95.2	95.2	95.5	99.1	99.2	103.0	101.0	95.3	98.0	102.7	99.2
Wind factor	12.3	14.0	13.2	8.8	0.2	4.4	3.4	2.0	2.6	7.7	11.1	12.8	7.4	3.3	7.2	13.0	7.7

TABLE 4.—*Number and percentage of flights made from New York to Chicago at or above different average speeds during the period June, 1921, to May, 1923, inclusive*

Speed (m. p. h.)	Time of flight	Number of flights: Spring	Summer	Autumn	Winter	Annual	Percentage of total number: Spring	Summer	Autumn	Winter	Annual
126	6.11	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
124	6.21	1	0	0	0	1	0.8	0.0	0.0	0.0	0.2
122	6.31	1	0	0	1	2	0.8	0.0	0.0	0.9	0.4
120	6.42	1	0	0	1	2	0.8	0.0	0.0	0.9	0.4
118	6.53	1	0	1	1	3	0.8	0.0	0.8	0.9	0.6
116	6.64	1	0	1	2	4	0.8	0.0	0.8	1.8	0.8
114	6.75	1	0	1	2	4	0.8	0.0	0.8	1.8	0.8
112	6.88	5	0	1	3	9	3.8	0.0	0.8	2.7	1.7
110	7.00	9	0	1	5	15	6.8	0.0	0.8	4.5	2.8
108	7.13	12	0	6	5	23	9.0	0.0	4.5	4.5	4.3
106	7.26	18	2	8	7	35	13.5	1.3	6.0	6.4	6.6
104	7.40	23	5	11	13	52	17.3	3.3	8.3	11.8	9.8
102	7.55	27	8	15	16	66	20.3	5.2	11.3	14.5	12.5
100	7.70	37	15	20	21	93	27.8	9.8	15.0	13.6	17.6
98	7.86	46	24	25	26	121	34.6	15.7	18.8	23.6	22.9
96	8.02	53	34	30	33	150	39.8	22.2	22.6	30.0	28.4
94	8.19	60	47	38	37	182	45.1	30.7	28.6	33.6	34.4
92	8.37	75	56	48	49	228	56.4	36.6	36.1	44.5	43.1
90	8.56	85	77	58	54	274	63.9	50.3	43.6	49.1	51.8
88	8.75	90	96	71	57	314	67.7	62.7	53.4	51.8	59.4
86	8.95	98	102	80	66	346	73.7	66.7	60.2	60.0	65.4
84	9.17	103	114	90	76	383	77.4	74.5	67.7	69.1	72.4
82	9.39	110	125	100	85	420	82.7	81.7	75.2	77.3	79.4
80	9.62	116	133	114	91	454	87.2	86.9	85.7	82.7	85.8
78	9.87	120	139	119	94	472	90.2	90.8	89.5	85.5	89.2
76	10.13	126	150	125	101	502	94.7	98.0	94.0	91.8	94.9
74	10.41	130	151	127	103	511	97.7	98.7	95.5	93.6	96.6
72	10.69	132	153	128	104	517	99.2	100.0	96.2	94.5	97.7
70	11.00	133	153	130	106	522	100.0	100.0	97.7	96.4	98.7
68	11.32	133	153	132	107	525	100.0	100.0	99.2	97.3	99.2
66	11.67	133	153	133	109	528	100.0	100.0	100.0	99.1	99.8
64	12.03	133	153	133	109	528	100.0	100.0	100.0	99.1	99.8
62	12.42	133	153	133	109	528	100.0	100.0	100.0	99.1	99.8
60	12.83	133	153	133	110	529	100.0	100.0	100.0	100.0	100.0

TABLE 5.—*Number and percentage of flights made from Chicago to New York at or above different average speeds during the period June, 1921, to May, 1923, inclusive*

Speed (m. p. h.)	Time of flight	Number of flights: Spring	Summer	Autumn	Winter	Annual	Percentage of total number: Spring	Summer	Autumn	Winter	Annual
156	4.93	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
154	5.00	0	0	0	1	1	0.0	0.0	0.0	0.9	0.2
152	5.07	0	0	0	1	1	0.0	0.0	0.0	0.9	0.2
150	5.13	0	0	0	1	1	0.0	0.0	0.0	0.9	0.2
148	5.20	0	0	0	1	1	0.0	0.0	0.0	0.9	0.2
146	5.27	0	0	0	1	1	0.0	0.0	0.0	0.9	0.2
144	5.35	0	0	1	2	3	0.0	0.0	0.8	1.8	0.6
142	5.42	0	0	1	2	3	0.0	0.0	0.8	1.8	0.6
140	5.50	0	0	1	2	3	0.0	0.0	0.8	1.8	0.6
138	5.58	0	0	1	4	5	0.0	0.0	0.8	3.6	0.9
136	5.66	1	0	3	6	10	0.8	0.0	2.3	5.5	1.9
134	5.75	1	0	4	7	12	0.8	0.0	3.0	6.4	2.3
132	5.83	2	0	4	8	14	1.5	0.0	3.0	7.3	2.6
130	5.92	4	0	4	8	16	3.0	0.0	3.0	7.3	3.0
128	6.02	8	0	7	10	25	6.0	0.0	5.3	9.1	4.7
126	6.11	9	0	9	15	33	6.8	0.0	6.8	13.6	6.2
124	6.21	13	0	10	20	43	9.8	0.0	7.5	18.2	8.1
122	6.31	20	0	14	23	57	15.0	0.0	10.5	20.9	10.8
120	6.42	24	1	16	31	72	18.0	0.7	12.0	28.2	13.6
118	6.53	25	1	20	38	84	18.8	0.7	15.0	34.5	15.9
116	6.64	30	1	27	44	102	22.6	0.7	20.3	40.0	19.3
114	6.75	36	2	33	52	123	27.1	1.3	24.8	47.3	23.3
112	6.88	42	3	41	57	143	31.6	2.0	30.8	51.8	27.0
110	7.00	47	10	44	63	164	35.3	6.5	33.1	57.3	31.0
108	7.13	51	15	58	67	191	38.3	9.8	43.6	60.9	36.1
106	7.26	59	26	63	74	222	44.4	17.0	47.4	67.3	42.0
104	7.40	71	37	67	79	254	53.4	24.1	50.4	71.8	48.0
102	7.55	84	52	71	88	295	63.2	34.0	53.4	80.0	55.8
100	7.70	91	65	81	93	330	68.4	42.5	60.9	84.5	62.4
98	7.86	93	77	88	352	94	69.9	50.3	66.2	85.5	66.5
96	8.02	99	80	97	95	371	74.4	52.3	72.9	86.4	70.0
94	8.19	106	90	104	97	397	79.7	58.8	78.2	88.2	75.1
92	8.37	111	100	109	101	421	83.5	65.4	82.0	91.8	79.6
90	8.56	114	112	117	106	449	85.7	73.2	88.0	96.4	84.9
88	8.75	121	124	122	108	475	91.0	81.0	91.7	98.2	89.8

TABLE 5.—*Number and percentage of flights made from Chicago to New York at or above different average speeds during the period June, 1921, to May, 1923, inclusive*—Continued

Speed (m. p. h.)	Time of flight	Number of flights					Percentage of total number				
		Spring	Summer	Autumn	Winter	Annual	Spring	Summer	Autumn	Winter	Annual
86	8.95	123	132	123	109	487	92.5	86.3	92.5	99.1	92.1
84	9.17	127	139	127	110	503	95.5	90.8	95.5	100.0	95.1
82	9.39	128	142	128	110	508	96.2	92.8	96.2	100.0	96.0
80	9.62	130	144	129	110	513	97.7	94.1	97.0	100.0	97.0
78	9.87	131	146	132	110	519	98.5	95.4	99.2	100.0	98.1
76	10.13	133	146	132	110	521	100.0	95.4	99.2	100.0	98.5
74	10.41	133	150	132	110	525	100.0	98.0	99.2	100.0	99.2
72	10.69	133	151	132	110	526	100.0	98.7	99.2	100.0	99.4
70	11.00	133	152	133	110	528	100.0	99.3	100.0	100.0	99.8
68	11.32	133	152	133	110	528	100.0	99.3	100.0	100.0	99.8
66	11.67	133	152	133	110	528	100.0	99.3	100.0	100.0	99.8
64	12.03	133	153	133	110	529	100.0	100.0	100.0	100.0	100.0

Tables 4 and 5 correspond to Tables 12 and 13 respectively of the former report and indicate the seasonal and annual number and percentage of flights made between New York and Chicago at or above the different average speeds. The annual percentages shown in the last column of Tables 4 and 5 are plotted in Figures 1 and 2, respectively. In figure 3 is given the resulting annual frequency of winds of different speeds, as derived from the preceding data. The winds determined from kite and pilot balloon records, as indicated in Figure 7 of the former paper, are also shown. Exactly the same

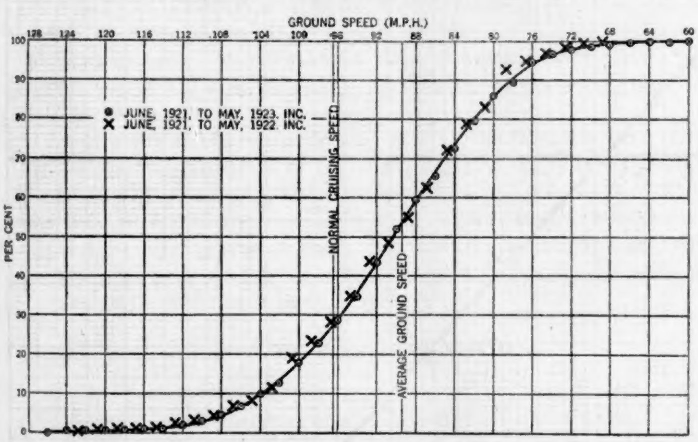

FIG. 1.—Percentage of trips made from New York to Chicago, 770 miles, at different average speeds with airplanes whose normal cruising speed is 96.5 miles per hour

assumption with regard to the increase in cruising speed of the planes is made as previously explained, viz, as opposing winds of increasing strength are encountered pilots advance the engine throttle until, against the extreme winds, a high speed is maintained approximately 15 per cent greater than the normal cruising speed shown in Table 2.

The data for the second fiscal year alone, June 1, 1922, to May 31, 1923, inclusive, are presented in Table 3 for comparison with the data of the former year and with the combined two-year record given in Table 2 above.

A comparison of the preceding data with those of the former report reveals several features of considerable interest:

THE WIND FACTOR

	M. p. h.
Air mail, fiscal year 1922	6.6
Air mail, fiscal year 1923	7.7
Air mail, two years combined	7.2
Kite and pilot-balloon data	7.4

These figures show that, as the period covered by the air mail records is extended, the wind factor determined therefrom approaches more and more closely the resultant wind computed from kite and pilot balloon observations. The wind factor adopted in the earlier paper was 7 m. p. h.; apparently, the correct value is nearer 7.3.

PERCENTAGE OF FLIGHTS AT DIFFERENT AVERAGE SPEEDS

As already stated, the values in the last columns of Tables 4 and 5 are plotted in Figures 1 and 2, respectively.

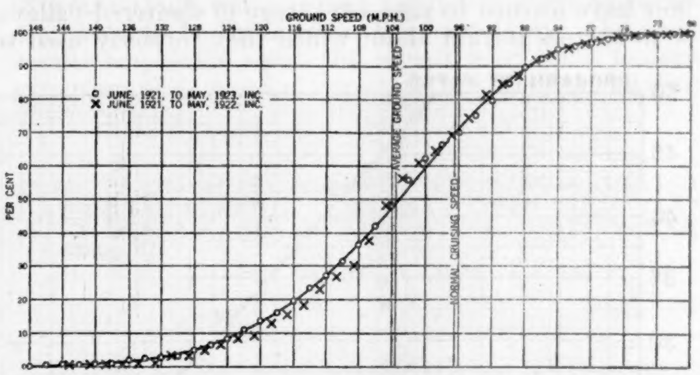

FIG. 2.—Percentage of trips made from Chicago to New York, 770 miles, at different average speeds with airplanes whose normal cruising speed is 96.5 miles per hour

When these are compared with Figures 2 and 3 in the earlier paper, a remarkable similarity is noted. If allowance is made for the slight increase in the normal cruising speed from 93.8 m. p. h. in the first year to 96.5 m. p. h. in the two years combined, the curves very nearly superimpose. In order to facilitate the comparison the values upon which the one-year curves are

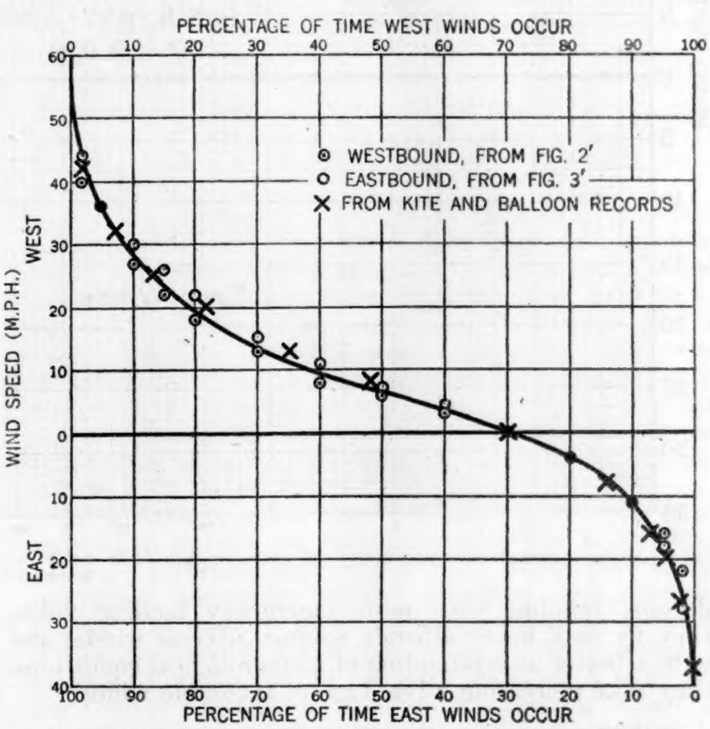

FIG. 3.—Annual percentage occurrence of east and west component winds of different speeds at 1,500 feet altitude along the New York-Chicago route

based have been indicated by crosses (×) on Figures 1 and 2. It is then seen that the effect of winds upon the ground speed of the planes (*a*) agrees almost exactly at the extremes in the two periods and (*b*) is increased 1 to 2 m. p. h. at the two "points of inflexion" and tends on the average to approach more closely the wind curve from kite and balloon data, as the period increases.

No material change is shown in the relative proportion of east and west component winds, viz, about 30 and 70 per cent, respectively.

The planes and motors used in the second year are of the same type as those used in the first. The slightly higher normal cruising speed can not therefore be attributed to aerodynamic causes. More likely it is an index of the increased efficiency resulting from the pilot's experience and familiarity with the motors and with the route. They lose less time wandering off the course; they have learned to take advantage of sheltered valleys, or now cross terrain about which they formerly used to detour; familiar with more emergency landing fields, they fly at a lower altitude against adverse winds; and with a better understanding of meteorological conditions, they take increasing advantage of favorable winds.[3]

FREQUENCY OF WINDS OF DIFFERENT SPEEDS

A comparison of Figure 3 with Figure 7 of the earlier paper shows:

(*a*) Very close agreement, especially with regard to the extreme winds;

(*b*) For the winds of moderate strength, the two-year average brings the curve 1 to 2 miles per hour nearer the values obtained by kite and pilot balloon observations;

(*c*) The relative proportion of east winds to west winds—namely, 30 per cent and 70 per cent—now agrees almost exactly for all three methods of determination;

(*d*) The strength of east or west winds which occur 5 per cent of the time is practically as found before: 36 m. p. h. from the west and 18 m. p. h. from the east; and

(*e*) The ordinate at the 50 per cent point is approximately 7 m. p. h. from the west, the wind factor again.

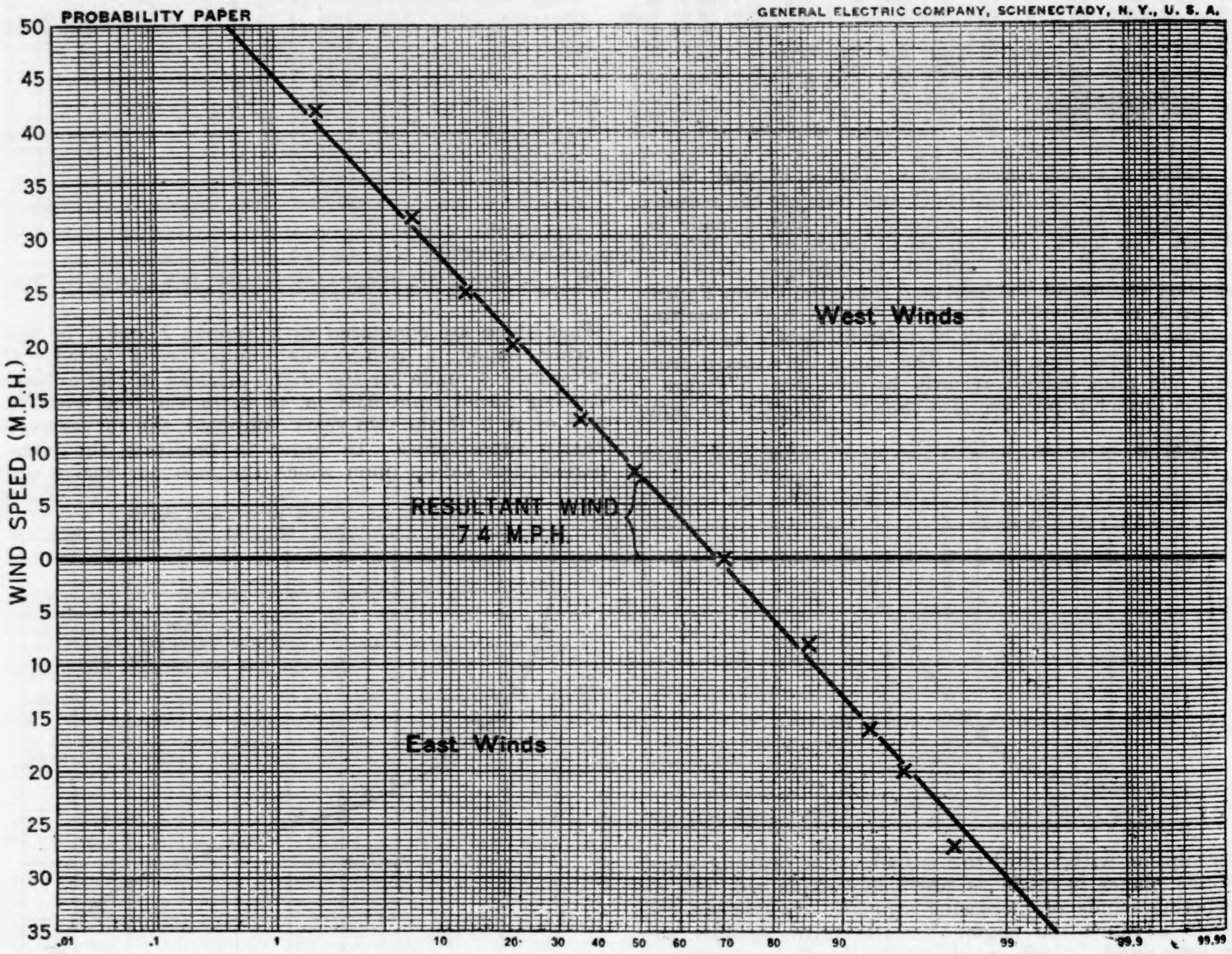

FIG. 4.—Annual percentage occurrence of east and west component winds of different speeds at 1,500 feet altitude along the New York-Chicago route, as determined from kite and pilot-balloon records

THE LAW OF PROBABILITY APPLIED TO THE FREQUENCY OF FREE-AIR WINDS OF DIFFERENT SPEEDS

It will be noted that the curve in Figure 3 is symmetrical about the point of intersection with the 50 per cent ordinate; that is, occurrence of winds with a velocity greater or less than the resultant wind becomes increasingly less frequent the further the strength of the winds departs from the mean value on either side. In other words, Figure 3 bears a striking resemblance to a "probability curve" and suggests that the frequency of occurrence of winds of different speeds may be expressed in terms of the well-known laws of probability.[4]

The general mathematical relation between a quantity v (in this case the velocity of the wind) and the proba-

[3] Of interest in this connection is the following statement from *The Aeroplane*, Feb. 20, 1924, p. 152, with reference to the Moscow-Konigsberg line: "On account of the better utilization of the favorable air currents, the average speed was increased this year in comparison with last year by 2.5 per cent; that is, from 137 km. (85 miles) to 141 km. (87 miles) per hour."

[4] The authors are indebted to Dr. A. R. Stevenson, jr., and Mr. C. Dantsizen, of the research department of the General Electric Co., for this interesting suggestion; also for calling attention to the use of "probability paper," discussed farther on in this paper.

bility, or frequency of its occurrence, P, is given by the equation:[5]

$$P = ke^{-h^2 v^2}$$

where h and k are constants.

If the law of probability does actually govern the distribution of the velocities of the different winds, the graph of Figure 3 must conform to the above general equation. A convenient method of determining this is by means of what is known as "arithmetic probability paper," whereon a probability curve, or curve of frequency, when plotted, will appear as a straight line.[6]

The frequency of east and west component winds of different speeds as found by kite and pilot-balloon records has therefore been replotted on probability paper and the result is shown in Figure 4. The points all lie remarkably closely along a straight line, the greatest deviation in observed frequency being 2.5 per cent, while the deviation in general is less than 1 per cent.

For this particular route, therefore, we have experimental evidence that the probability of occurrence of an east or west wind component of given speed may be predicted with surprising accuracy, by the law of probability, from the observed frequency of winds of other speeds. If this relationship between the velocity of a free-air wind and the probability of its occurrence can be shown to have general application for other routes as well, a powerful method is disclosed for the prediction of winds of different speeds when sufficient data are at hand to determine the trend of the probability curve. A preliminary examination of free-air wind data for other parts of the country indicates the correctness of this hypothesis.

In the present instance the winds, as determined from an increasing number of air mail flights, tend to approach more and more closely the winds as found by kite and pilot balloon observations. This is exactly what we should expect if the actual winds (as would be disclosed from an indefinite number of observations), really do vary in accordance with the law of probability.

SUMMARY AND CONCLUSIONS

1. An extension of the analysis of air mail records to cover two consecutive years of operation between New York and Chicago indicates that the winds as determined in the previous analysis from more limited data are substantially correct.

2. In general, the winds determined from an increasing number of flight records tend to conform more closely to the winds as found by kite and pilot balloon observations. The tendency is particularly evident in the determination of the wind factor.

3. A theoretical explanation of this improved agreement is suggested by the resemblance of the wind graph to a probability curve. The frequency of occurrence of winds of different speeds, as shown by aerological observations, is found to agree remarkably closely with the probability of such occurrence as predicted by the law of probabilities. This agreement suggests that the distribution of the velocities of free-air winds may be found in general to be governed by the probability law, in which case a powerful method is disclosed for predicting the frequency of a given wind speed when complete information is not at hand.

4. An interesting improvement in the general performance of the air mail planes is revealed by an increase of several miles per hour in the average cruising speed. This is indicative of the type of improvement which may be expected in an air transportation service as experience in operation is accumulated.

5. In view of the importance of an accurate knowledge of winds along routes where regular aircraft operations are likely to be initiated in the near future, the above results emphasize again the urgent need for a material extension of aerological investigations to cover all parts of the country.

[5] Merriman, Mansfield. Method of Least Squares. New York, 1915, p. 25

[6] For a discussion of the construction and use of this paper, see "Storage to be Provided in Impounding Reservoirs for Municipal Water Supply," by Allen Hazen. Trans. of Amer. Soc. of Civil Engineers, vol. 77, pp. 1539-1667, 1914; also, "The Element of Chance in Sanitation," by George C. Whipple. Journ. Franklin Inst., vol. 182, pp. 37-59, 205-227, 1916.

RESULTS OF MEASUREMENTS OF SOLAR RADIATION AND ATMOSPHERIC TURBIDITY OVER THE ATLANTIC OCEAN AND IN ARGENTINA.—PRELIMINARY REPORT

By Dr. FRANZ LINKE

[Translated from manuscript text in German by W. W. Reed, Weather Bureau Washington, D. C., January 7, 1924]

1. *Data on the expedition.*—April 5, 1923, departure from Hamburg on the *General San Martin*; May 2, arrival at Buenos Aires; beginning of May to the beginning of July, journeys in Argentina; July 15, departure from Buenos Aires on the *Hindenburg*; August 15, arrival at Hamburg.

2. *Instruments.*—Universal actinometer of Hartmann & Braun of Frankfort on the Main, made according to special plans with a red-glass filter having a thickness of 3.02 mm. (Schott F. 4512) and range of transmissibility from 600 to 2,000 $\mu\mu$. Incandescent-lamp photometer with sodium cell of Günther & Tegetmeyer, Brunswick, with Wulf's bifilar electrometer and condensers of Siemens & Halske having capacity of 2, 0.5, and 0.1 microfarads. Blue scale for the estimation of sky color (mixture of white and Prussian blue) issued by the Unesma, Leipzig. Portable aspiration psychrometer of R. Fuess, Steglitz.

Previous to the departure from Hamburg, frequently in Argentina, and after the return from the expedition the actinometer was compared with an Ångström compensation pyrheliometer that had been adjusted to the revised (1913) Smithsonian scale by W. Marten at Potsdam. Unfortunately the condensers, which are necessary for incandescent-lamp radiation measurements with electrometers (galvanometers of requisite sensitiveness are not practicable on expeditions), gradually lose their state of insulation in the Tropics, so that great difficult is met with in the work.

3. *Methods of observation.*—Measurements were made only when the sun was unquestionably free of cloud and at every favorable time of the day. These were carried out more frequently in the mornings and evenings; during the midday hours long interruptions occurred. The apparatus for measuring radiation was exposed on shipboard on the roof of the pilot house on a table having Cardan's method of suspension (swinging table). All observations were made by me. At each reading the altitude of the sun was determined with the sextant. Observations of air pressure, temperature, and relative humidity were made several times daily. On the outward and on the return voyage when the sun was at its zenith position measurement was made of sky brightness for the spectrum range of the sodium cell (maximum sensitiveness about 360 $\mu\mu$.

The blue scale contained 8 color tones from white to ultramarine blue, and estimation was made to halves of the scale. No. 3 was white; No. 10, ultramarine blue.

The deepest blue (No. 9) was observed in La Quiaca at the boundary between Argentina and Bolivia, about 3,700 meters above sea level.

4. *Methods of calculation.*—The air mass (m) through which radiation passed was determined, for the measured altitude of the sun, from Bemporad's table with reduction to a pressure of 760 mm. The turbidity factor (T) was measured according to the extinction formula [1] developed by me on the basis of a solar constant value of 1.932, taking into consideration the earth's solar distance. From the observations with the actinometer and the photometer there were interpolated, as far as the observations might permit, both the values for m = 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 8.0, and 10.0, and also, with good daily series, those for the different hours of the day. The interpolation was made graphically on the logarithmic paper of Schleicher & Schull, No. 367½ ST. K. For the zones and points designated in Table 1 mean values were derived from these interpolated values in the usual way.

TABLE 1.—*Radiation intensity, turbidity, and sky color*

	Radiation intensity		Turbidity factor T [2]	Absolute humidity (e)	Blueness of sky (scale 3-10)	Part of turbidity factor due to dust, etc.
	m=1 cal.	m=3 cal.				
				mm.		
Dunkelmeer [1]	1.126	0.527	4.22	18.1	4.7	2.61
Calm zone	1.332	0.794	2.91	19.3	5.7	1.20
North Temperate Zone	1.393	0.882	2.56	9.7	5.7	1.21
South Temperate Zone	1.455	0.978	2.22	15.9	6.7	0.64
Northeast trades	1.455	1.004	2.14	14.2	6.6	0.50
Southeast trades	1.464	0.994	2.17	18.0	6.9	0.51
Argentina, cities [2]	1.481	1.021	2.08	6.0	6.5	0.86
Argentina, country [3]	1.590	1.213	1.52	3.0	7.1	0.41
Andes [4]	1.594	1.235	1.46	2.2	8.0	0.38
Bolivian plateau [5]	1.624	1.274	1.36	0.6	8.0	0.25

[1] Off Cape Verde Islands.
[2] La Plata and Mendoza.
[3] Pilar, near Cordoba.
[4] Puente del Fuca, 2,700 meters.
[5] La Quiaca, 3,600 meters.

5. *Results of measurements of total radiation.*—Columns 2 and 3 in Table 1 give the means of the interpolated radiation values in gram calories per square centimeter per minute for the zenith distance of the sun corresponding to m = 1 and m = 3; column 4 gives the turbidity factor for the solar altitude 19.3° (zenith distance, 70.7°), corresponding to m = 3, which is almost always reached in the Temperate Zone. Column 5 gives the mean absolute humidity (e) in mm. of vapor pressure; column 6, the blueness of the sky. It is noted how well the blue coloring runs opposite to the turbidity factor. However, in the upper portion of the accompanying Figure 1, the turbidity factor and the absolute humidity show no significant connection.

In the regions where the turbidity was evidently caused by dust and other dry particles (*trockener Dunst*) as on the *Dunkelmeer*[2] on account of the desert dust carried from the Sahara by the northeast trade wind, in the north Temperate Zone in the English Channel, and on the coasts of France and Spain on account of winds from the land, and in the cities of Argentina, the observations show a degree of turbidity which exceeds that corresponding to the degree of humidity . In the remaining regions *the turbidity factor increases 0.047e for each millimeter of vapor pressure.*

[1] Meteorologische Zeitschrift, 1922, S. 161 ff.
[2] *Dunkelmeer*, the name given to the portion of the Atlantic Ocean between the Equator and the Madeira Islands extending from the coast of Africa to 39° west longitude *Meyers Konversations-Lexikon*.

If we assume with J. Hann that the total water content of the atmosphere over a square meter of surface is on an average 2.3e or, as F. E. Fowle computes it in depth of water in cm., $w = \frac{2.3e}{10}$, then there results an increase in the turbidity factor amounting to 0.20w. This agrees fairly well with a purely theoretical calculation in my first paper on the turbidity factor,[3] in which on the basis of the data by F. E. Fowle relative to the transmission coefficients of dry air and of water vapor I found $T_w = 1 + 0.16w$ (formulas 8 and 10). Thus the influence of the water vapor contained in the air may be eliminated, and since for ideally pure air the turbidity factor is by definition equal to 1, the influence of the "dry" turbidity (dust, smoke, salt, etc.) may be estimated if we subtract from the observed turbidity factor the value 1 + 0.16w, or 1 + 0.037e. The part of turbidity due to particles of dust, etc. (*trockener Dunst*), thus appears in column 7 of Table 1. In Table 2, I add some observations of the turbidity factor for central Europe in order to make a comparison possible.

TABLE 2.—*Turbidity in central Europe*

Station	Observed turbidity (T)	Absolute humidity (e)	Part of turbidity due to dust, etc.
Frankfort on the Main:		*mm.*	
Winter	3.08	4.9	1.90
Summer	3.79	9.9	2.62
Kolberg:			
Winter	2.18	4.3	1.02
Summer	2.94	10.3	1.57
Potsdam:			
Winter	1.99	4.0	0.84
Summer	2.72	10.3	1.35
Taunus Observatory:			
Winter	1.40	4.0	0.25
Summer	2.66	8.6	1.34
Davos:			
Winter	1.64	2.5	0.59
Summer	1.78	7.6	0.50

The values obtained, showing the part played by the dry constituents in the degree of turbidity of the atmosphere, appear to me to be not improbable. In any case this first attempt to divide the turbidity into the effect of the absorption by water vapor and that of reflection by the larger, solid particles (dust, smoke, salt, etc.) encourages further steps in this direction.

6. *Results of the measurements of red radiation.*—The percentage of the radiation of a given spectrum region is dependent chiefly on the air mass through which the radiation passes. We must, therefore, consider the dependence of the *amount of red radiation* on humidity and other factors *for given air masses.* The lower portion of Figure 2 shows the dependence on vapor pressure measured at the ground.

It is noted that with air masses 1, 3, and 5 there exists almost the same relation, namely, *that with each millimeter of vapor pressure the percentage of red radiation decreases 0.2 per cent.* With greater air masses this value is apparently somewhat larger, but closely proportional to the percentage of red radiation. If we now eliminate this thus determined influence of water vapor on the amount of red radiation then no influence of the dust, smoke, etc. (*trockener Dunst*), is longer recognizable. *The "dry" turbidity appears to influence the percentage of red radiation very little or not at all.*

(3) Beiträge zur Physik der freien Atmosphäre, Band 10, S. 91 ff.

L. Gorczyński,[4] who by chance made radiation measurements at the same time while on a voyage to Siam and Java, wrote me that the Equator and south of it he found a lower percentage of red radiation, which he is inclined to view as a peculiarity of the Tropics. According to my measurements it is explained that this is only an effect of the greater amount of water vapor in the air.

7. *Results of the measurements of short-wave radiation.*—As already stated the constants of the incandescent-lamp photometer (with sodium cell) changed, unfortunately, many times. It seems, however, that this short-wave light is influenced chiefly by the dust, smoke, etc. (*trockener Dunst*), contained in the atmosphere and less by the water content. Yet I do not venture to give a numerical statement.

8. *Selective absorption by water vapor.*—From the results mentioned in section 6 it is also possible to determine the influence of selective absorption by water vapor, which lies almost entirely in the red and intra-red regions of the spectrum, on the water content. On the basis of the values for each wave length of extra-terrestrial radiation and for the transmission coefficients of pure air and of water vapor determined by C. G. Abbot and F. E. Fowle there may be found for each mass (m) a theoretical value for the dependence of the percentage of red radiation on the increasing amount of water vapor content, which (value), according to the values of a_w derived by E. F. Fowle, does not include, however, the selective absorption.

If we designate the red content by r_w when the water content is w (in cm.) and by r_o when the air is dry, then $r_w - r_o = \Delta r = \alpha w r_o$. Instead of this theoretical value α, which for $m=1$ would have the value 0.0097 we now find the value $\alpha' = 0.0145$, in which α' includes the *selective absorption.* The influence of the selective absorption (dark bands) on the percentage of red radiation is thus $\Delta r = (\alpha' - \alpha) w r_o = 0.0048 w r_o$, in which r_o with this red-glass filter has for $m=1$ the value 56.2, and for $m=3$ and $m=5$ the values 62.5 and 66.6, respectively. Unfortunately this result for Δr is uncertain by about 5 per cent.

9. *The daily march of the turbidity factor.*—Measurements of this kind extending over the whole day gave almost always an increase in turbidity factor till midday followed by a decrease till evening; on an average the values for the afternoon are greater than those for the forenoon, whence it follows that over the ocean also there occurs an increase during the day.

TABLE 3.—*Daily march of the turbidity factor (T.)*

	8 a. m.	9 a. m.	10 a. m.	11 a. m.	Noon	1 p. m.	2 p. m.	3 p. m.	4 p. m.
Dunkelmeer	3.43	3.50	3.68	3.77	3.83	3.84	3.83	3.80	3.73
North Temperate Zone	2.74	3.01	3.06	3.12	3.14	3.08	3.04	2.96	2.86
South Temperate Zone	2.22	2.36	2.54	2.61	2.65	2.60	2.55	2.46	2.30
Northeast trades	2.24	2.36	2.49	2.54	2.56	2.56	2.54	2.46	2.38
Southeast trades	2.28	2.44	2.52	2.55	2.57	2.56	2.52	2.40	2.25
Argentina, country	1.42	1.48	1.55	1.56	1.58	1.62	1.61	1.59	1.50
Andes, at 2,700 m	1.38	1.49	1.59	1.64	1.66	1.67	1.66	1.60	1.45
Bolivian plateau (3,600 m.)	1.35	1.42	1.42	1.42	1.44	1.46	1.45	1.44	1.38

If the afternoon values were not higher than those for the forenoon there would be the obvious assumption that the values of a_m cited by me in the calculation of T. (*loc. cit.*) were inaccurate since on the one hand they are based on the by no means certain values for extra-terrestrial radiation and transmission coefficient for pure, dry air calculated at the Astrophysical Observatory, Washington, and since on the other hand the selective absorption could not be taken into consideration for lack of data. So an explanation of the increase in turbidity around midday must be sought.

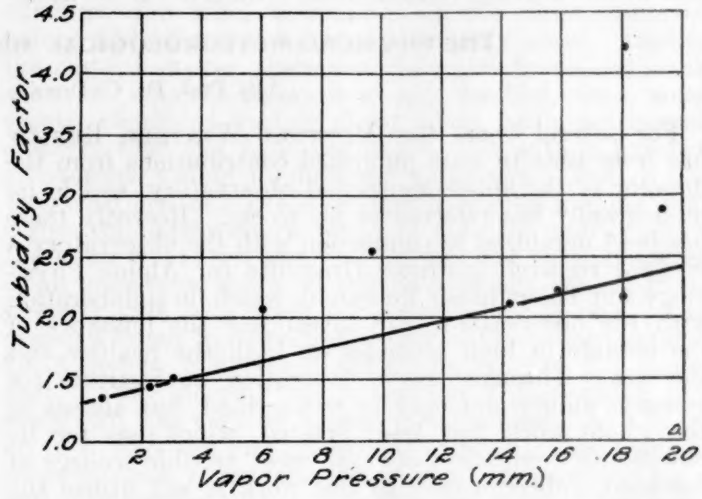

FIG. 1.—Dependence of the turbidity factor (T) on vapor pressure (*e*)

I have come to the conclusion that, as the result of the daily vertical convection in the lower air strata, there occurs at the upper limit of this convection stratum an increase in relative humidity and with it an increase in the size of the condensation nuclei whereby the latter

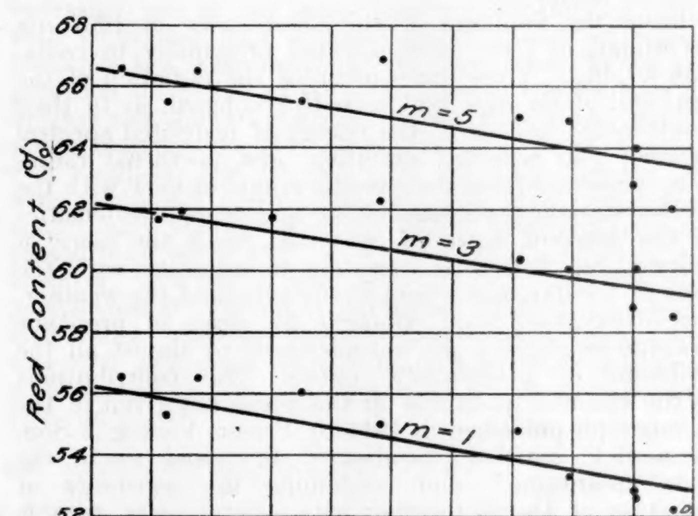

FIG. 2.—Dependence of the red content (*r*) of solar radiation on vapor pressure (*e*)

are enlarged beyond the wave length of light and thereafter totally reflect a portion of the direct solar radiation. This turbidity becomes recognizable even before the appearance of the clouds through the strong Tyndall effect of such dust-filled air which is near the point of saturation (pre-condensation stage).

I hope to be able to report in greater detail on this and other results in *Band 5, "Berichte des Meteoroligisch-*

[4] "Sur la diminution de l'intensité dans la partie rouge du rayonnement solaire, observee entre l'Europe et l'Equateur" (Comptes Rendus, Paris, 1923, p. 754). See also Mo. WEATHER REV., October, 1923, 51: 528.

geophysikalischen Institutes," Frankfort on the Main, as soon as funds for publication are available. Only one result is to be given here.

10. *Relative values of sky radiation in the spectrum range of the sodium cell with the sun at the zenith.*—There are available four series of measurements which agree very well, so that the considerations previously mentioned do not hold for these relative values. The zone just at 30° altitude radiates least strongly. If we designate the value for this point by 100 then there appears the following distribution:

Altitude	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°
Sky radiation	114	112	108	104	101	100	102	106	109	113	119	128	144	230	312	*500

*Approximate.

NOTE.—This expedition was supported by the *Ministerio de agriculture, Republica Argentina,* the Stinnes Steamship Lines, and the *Verein der Freunde des Taunus-Observatoriums,* Frankfort on the Main.

THE PHYSICAL-METEOROLOGICAL OBSERVATORY AT DAVOS, SWITZERLAND

By Prof. Dr. C. DORNO, Director of the Observatory

For several years the MONTHLY WEATHER REVIEW has from time to time published contributions from the director of the above-mentioned observatory, and in its bibliography has referred to his works. Recently there has been organized in connection with the observatory a medical research institute (Institute for Alpine Physiology and Tuberculosis Research), which, in collaboration with the observatory, will investigate the influence of the climate in high altitudes on both the healthy and the sick. Through this collaboration an institute for research unique not only in Switzerland, but almost in the whole world has been created, which has for its object the combating of that most terrible scourge of mankind, tuberculosis. In this work it will utilize the rich clinical material which is frequenting the world-renowned health resort of Davos. The director of the medical institute is Professor Loewy, the collaborator for many years of Professor Zuntz and he is at the same time in charge of the physiological laboratory. The pathologic-bacteriological department, which will be entirely independent, is still being enlarged and will soon be completed.

From the founding of the observatory in 1907, its investigations have been directed principally to radiation studies. These have included the radiation of the sun, and of the sky, and of both combined, as to their total energy and as to the energy of restricted spectral regions; also reflected radiation, and nocturnal radiation. Starting from the climatic points of view with the merely statistical problem of the quantities or intensities of the different kinds of rays that reach the place of observation, and their variation in intensity with the hour of the day, the season of the year, and the weather, the observatory soon enlarged its series of problems towards geophysics, and automatically to almost all the problems of atmospheric optics. The contributions to the climatic questions on the whole are given in the monograph published in 1911 by Friedr. Vieweg & Son, Brunswick, entitled "Studies on light and air of the high mountains," and containing the constants of radiation of Davos together with several years' records of the atmospheric-electrical elements and radioactive values. The former have been amplified and perfected in the subsequent years after the introduction of the photo-electric method. The Meteorologische Zeitschrift and the Physikalische Zeitschrift have published reports thereon. The program adapted to the "studies," which has also been described and discussed in other publications, has been followed in the researches of the radiation climate of other places, such as Kolberg, St. Blasien, recently also Arosa, Agra (Tessin), and even to a certain extent in the United States of North America. Atmospheric optics has claimed and obtained rightful recognition in the voluminous works "Phenomena of twilight and corona around the sun" and "Himmelshelligkeit, Himmelspolarisation und Sonnenintensität in Davos, 1911 bis 1918" which appeared in 1917 and 1919 in the Abhandlung des Preussischen Meteorologischen Institutes, Vol. V and Vol. VI. The latter work aims at uniformly comprehending the whole economy of atmospheric light, that is to say, establishing what has become of the incident solar radiation, and what sort of changes it has undergone with regard to intensity, polarization, and color. The years from 1919 to 1921 have been devoted to the perfection of recording methods on the basis of the methods employed only for individual measurements in the foregoing years. These efforts arrived at an almost complete success, as has been shown in "Progress in radiation measurements" published in the MONTHLY WEATHER REVIEW in 1922, according to which Davos is the first place in the world to continuously record the total exchange of heat by radiation during the course of a whole year.

After such successful work the observatory, founded and maintained by the director's own means, would have been forced to close in consequence of the depreciation of his German properties, had not, it may be said, all Switzerland—the Swiss Association for Naturalistic Research, Swiss Society for Climatology and Balneology, Swiss Red Cross, canton and community authorities, Cantonal Medical Association and others—(the subvention on the part of the Swiss Confederation is positively promised) undertaken to aid the observatory, and amplify it by a medical institute, as already described. Affiliated with the institute, but entirely free and independent with reference to its working methods, management, and name, as well as in its unaltered situation, the observatory exists independently by the side of the institute. Professor Dorno has been named an honorary member of the institute and member of the board. There is much to be hoped for in the future collaboration of meteorology, physics and physiology, more particularly as the place of observation, in the high mountains, is to be considered the most favorable for such combined investigations. Dorno's works published in the years 1922 and 1923, "About specific-medical climatology," "On the connection between the extension of the ultra-violet solar spectrum and the formation of pigment," and others, indicate the first directives to be followed by these works of collaboration, by the side of which the old aims of the observatory are being pursued in an unaltered manner.

About the foundation, organization, and the objects of the Institute of Physiology it may be briefly said: The board is composed of nine members, of whom five are to be medical men or naturalists. To the institute there is attached a scientific body giving advice and offering collaboration, being composed of professors of the Swiss universities, not only of medical men, but also representatives of the meteorological and physical faculty

of Zurich University. Scientific men proposed by the scientific council are in the first instance admitted to working places, and also other investigators of any nationality. A branch station is connected with the institute and the observatory well equipped and in the best imaginable situation at a height of 2,500 meters on Muottas-Muraigl near Samaden (Engadine), easily accessible by a funicular railway. The publications issued having their origin in researches supported by the funds of the institute will bear in their title a notice referring thereto. For the equipment of the institute so far 55,000 Swiss francs are available (wherein the value of the instruments of the observatory valuated at 80,000 Swiss francs is not comprised), and the budgets of the first year amount to 57,000 Swiss francs.

On January 3 to 5, 1924, a belated modest inauguration took place, in which the Federal, cantonal, and communal authorities, representatives of the universities of Zurich, Basel, Bern, and of the scientific council composed of professors of the Swiss universities and of physicians, took an active part.

A METEOROLOGIST AT SEA

Dr. C. F. Brooks, associate professor of meteorology and climatology at Clark University, Worcester, Mass., recently made a voyage to the West Indies for the threefold purpose of (1) observing winter weather and its effects on the people, (2) obtaining a series of comparative surface water temperature and weather observations, and (3) determining the best method of making sea surface temperature observations. A report of the investigation will appear in a subsequent issue of the MONTHLY WEATHER REVIEW.

During the last stage of the return voyage, when the vessel on which Doctor Brooks was a passenger, the *Empress of Britain*, was proceeding from Bermuda to New York, a storm of considerable proportions was encountered, Doctor Brooks has prepared the following account of this storm, which is of special interest as coming from a meteorologist rather than a seaman. —Ed.

SOME NOTES ON THE WEATHER, MARCH 21-23, 1924, BERMUDA TO NEW YORK

By C. F. BROOKS

The weather on the 21st at Bermuda was very rainy; heavy showers of rain occurred, especially at about 10 a. m. and 1 to 2 p. m. The first shower marked the arrival of much warmer, moister air, and the second one came just before a very great increase in wind velocity, accompanying a shift in direction from SE. to SW. For about an hour around sunset the sky was clear. Then, however, low clouds formed as the wind shifted to WSW. A line of clouds marked with moderate to brisk showers passed over at about 8:40 p. m. at the time the wind shifted from WSW to W. Thereafter, the sky was partly cloudy with alto-cumulus and strato-cumulus, the wind increasing all the time. Shortly before midnight the sky was practically clear. During the night, however, there was more cloudiness and some showers. Shortly before 6 a. m., the 22d, there were ragged clouds at two or three levels, with patches of greenish blue sky here and there, and with a number of showers visible in different directions. The clouds thickened and at 8 presented a rather solid looking wall across the northwestern sky. At 8:40 the rain front of the main wind-shift line reached us, and three-quarters of an hour later the wind shifted suddenly from a fresh westerly gale to a fresh north-northeasterly one. The pressure began to rise rapidly from its low point of about 29.15 inches, maintained since 2 a. m. In the latter part of the morning the atmospheric pressure in my stateroom was varying up and down as much as 0.14 of an inch with the movement of the ship. This appears to have been a combination of the change in altitude with the passing waves, and also the relative compression in the ventilator as the ship rolled from side to side.

The sky remained continuously cloudy with strato-cumulus from which occasional showers fell till about noon when the sun began to shine now and then. During the early afternoon, though the strato-cumulus clouds looked very heavy, it was not possible to tell whether there were any light showers or not. There was an unceasing rain of salt spray over the ship all the time, with occasional falls of considerable masses of water. Later, as the temperature of the water rose, as we approached the center of the Gulf Stream, the sea became rougher and showers general. At the time of the highest water temperature (71) shortly after 6 p. m. the sea was roughest, the propellers of our ship coming out with practically every wave, and the cloud cover was denser and apparently more rainy. Immediately we passed from water at 71 into water of 54 at 7:30 p. m., however, the sea quieted considerably, and the sky partly cleared. The gale continued, however, for some hours more. Before sunrise the next morning the weather was clear and quiet, though there was still a moderate ground swell to give us a suggestion of the storm we had just run out of.

THE MOVEMENT OF THE CYCLONE OF MARCH 8, 1924, ACROSS TEXAS

ALFRED J. HENRY, Meteorologist

[Weather Bureau, Washington, April 17, 1924]

The type of pressure distribution shown in Figure 1 is one of particular interest to forecasters of the United States Weather Bureau; interesting because there is often a distinct hiatus in the path of cyclones that pass from the high plateau of New Mexico to the plains of Texas, and consequently a certain degree of uncertainty as to their future course and development.

It is a rather remarkable fact that extratropical cyclones in winter occasionally advance from the Pacific about north latitude 45° to 50° southeastward directly to Texas or the lower Mississippi Valley without apparently losing any kinetic energy. The rapidity of movement leads to the inference that friction with the exceedingly rugged topography of the path followed is absent and further that the bottom portion of the whirl is cut off as it crosses the mountains. In some way not clearly understood, the middle and top parts of the whirl conserve their original energy until they arrive in the region where warm moist currents are found in the levels next to the surface. So soon as that region is reached connection with the surface is again completed and the storm pursues its normal course with unabated energy.

In this particular case (see fig. 1[1]) the level of the barometer in the center of the cyclone is rather low and

[1] For the path of the cyclone here illustrated see track No. IV of chart 11, this REVIEW.

the cyclone is flanked on the north and west by much higher pressure and low temperature. After making allowance for errors in sea-level barometric reduction for elevated plateau stations there remains a rather steep barometric gradient for northerly winds in the region occupied by the cyclone center; the low surface temperature and the absence of moist air in the immediate front of the cyclone apparently make for an early dissolution of the disturbance. A second, and the more likely, alternative is that the cyclone center will be displaced far to the southeast by the inflow of cold northerly winds. Any displacement in that direction will bring it into regions where the natural atmospheric conditions are favorable to the development of cyclones.

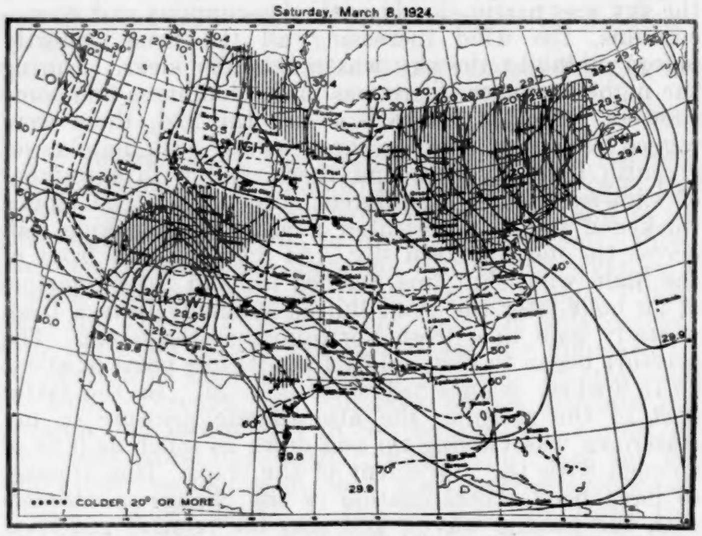

FIG. 1.—Daily weather map, 8 a. m., 75th meridian time; shaded areas indicate regions of rainfall in last 24 hours. Symbols showing state of sky at time of observation are given only for stations within the region covered by the cyclonic storm (the LOW)

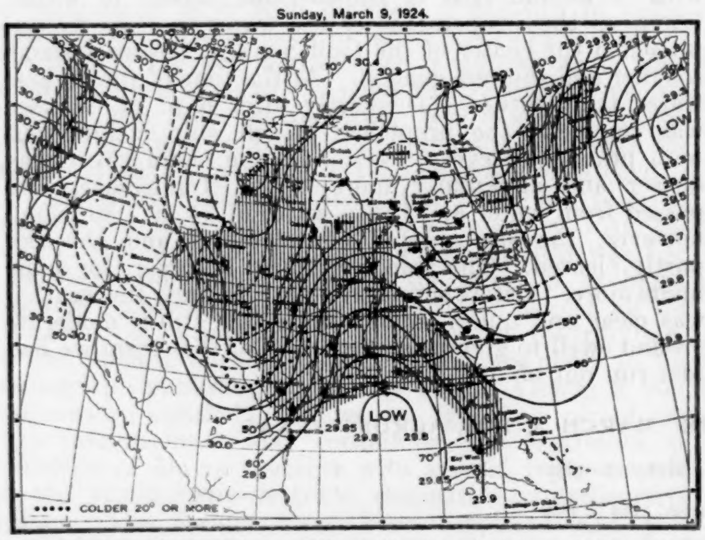

FIG. 2.—Daily weather map, 8 a. m., 75th meridian time; shaded areas indicate regions of precipitation in the last 24 hours; the state of the sky at time of observation is shown for stations around the storm center by the shading of the small circles; half-shaded indicates a sky half-covered, etc. R indicates rain, S snow falling at time of observation.

Free-air observations from instruments carried by kites are available from several stations within the probable path of the cyclone in question. The geographic coordinates of the stations are shown in the exhibit below:

Station	N. lat.		W. long.		Altitude
	°	′	°	′	*Feet*
Groesbeck, Tex	31	30	96	28	461 (141 m.)
Broken Arrow, Okla	36	2	95	49	765 (233 m.).
Due West, S. C	34	21	82	22	711 (217 m.).
Royal Center, Ind	40	53	86	29	736 (224 m.).

I have assembled in Table 1 such free-air observations as were obtained on March 8–9, when the cyclone in question was approaching and passing the stations named. Figure 1 shows that while the cyclone center was in New Mexico a great cloud sheet had covered Texas and other regions to the eastward of the center. Rain had set in at Dallas, Taylor, and San Antonio, Tex., and snow was falling in eastern Colorado, southeastern Wyoming, and locally in Nebraska, Kansas, and Missouri.

The free-air observations.—From Table 1 it will be noted that surface winds in Oklahoma and Texas were from an easterly quarter and shallow and that at both Groesbeck and Broken Arrow they turned through S. to SSW. or SW. The top of the Groesbeck flight was reached at 2,255 m. and the wind at that level was from the SW. The flight at Broken Arrow reached an altitude of 3,590 m. where a SSW. wind prevailed. On March 9 after the cyclone had passed to the eastward N. and NW. winds prevailed up to the highest points reached by the kites at both stations.

TABLE 1.—*Free-air observations*

[Altitude in meters above m. s. l.; temperature in deg. C.]

GROESBECK, TEX.

	Sur.	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500
Mar. 8, T	12.3	12.5	11.8	10.3	8.8	7.4	4.8	------	------	------
Mar. 9, T	1.3	−1.9	−4.0	−2.6	−0.3	0.9	2.8	−0.7	------	------
Mar. 8[1], W	E.	SE.	SSE.	S.	S.	SSW.	SW.	------	------	------
Mar. 9, W	NNW.	NNW.	NNW.	NNW.	NNW.	NNW.	NNW.	W.	------	------

BROKEN ARROW, OKLA.

	Sur.	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500
Mar. 8,[2] T	0.0	−0.5	0.6	2.6	3.4	2.4	0.2	−3.2	−6.5	−9.9
Mar. 9, T	−4.6	−6.5	−8.3	−7.7	−8.4	−9.8	−9.7	−9.4	−11.0	------
Mar. 8, W	NE.	E	ESE.	SSE	S	SSW.	SW.	SSW.	SSW.	S.
Mar. 9, W	N.	N.	N.	N.	N.	NNW.	NW.	NW.	NW.	------

DUE WEST, S. C.

	Sur.	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500
Mar. 9,[3] T	5.6	6.2	6.4	4.7	3.0	1.4	−2.0	−5.3	------	------
Mar. 10, T	4.5	1.6	−0.9	−3.1	−5.5	−7.1	−10.7	------	------	------
Mar. 9, W	ENE.	E	SE.	SE.	SSE.	SSE.	SSE.	S.	------	------
Mar. 10, W	W.	W.	W.	W.	W.	WNW.	W.	------	------	------

ROYAL CENTER, IND.

	Sur.	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500
Mar. 9,[4] T	−1.0	−4.0	−6.8	−8.3	−9.2	−7.2	------	------	------	------
Mar. 9, W	E.	E.	E.	E.	ESE.	ESE.	------	------	------	------

[1] St. cu. from SW. throughout flight; base at 1,700 m. at 10 a. m.; rain at end of flight.
[2] Ci. and A. cu. west at beginning, changing to 10 A. cu. SW. at end of flight.
[3] 10 A. st. WSW. at beginning, changing to 4 A. st. WSW., 4 A. cu. SW., and 2 St. S. at end.
[4] Snow during flight.

The free-air temperatures on the 8th, when the cyclone center was about 800 miles distant, are shown for the several levels reached by the kites. At Groesbeck on the 8th there was a small inversion of temperature at 500 m.; above that level, although the winds were southerly, the temperature steadily decreased. The lapse rate was clearly less than the dry adiabatic. On the 9th the winds were NNW. except that at the top of the flight

a W. wind prevailed. This NNW. wind was considerably stratified as regards temperature, there being a cold stratum at 750 m. (−4.0° C.) above which temperature rose to a maximum of 2.8° C. at 2,000 m.; then followed a rather sharp fall as the wind backed to W.

At Broken Arrow on the 8th the winds up to 3,000 m. conform both as to direction and clockwise turning with those of Groesbeck. On the succeeding day they were more northerly than at Groesbeck.

The temperature of the free air at Broken Arrow on the 8th shows a weak minimum at the 500 m. level, and a distinct rise from that level to a maximum at 1,250 m.; thence to the top of the flight the temperature fell 13.3° C. in 2,250 m.—a not unusual fall in temperature—in southerly winds. On the following day with northerly winds the air column was uniformly colder, as would be expected, although the difference at the 3,000-m. level was but 4.5° C.

On March 9 (see fig. 2) the center of the cyclone was apparently off the mouth of the Mississippi, although its position is dependent upon the single barometer reading of New Orleans, La. It is evident that there was not a movement of translation from New Mexico on the 8th to the Gulf of Mexico on the 9th, but rather that a new cyclone developed in the southern end of the barometric trough that is present in Figure 1, paralleling the Rio Grande Valley. (See the isobar of 29.80 inches.)

Consider now the observations made at Due West, S. C., which on the 9th was in relatively the same position with respect to the cyclone center as Groesbeck and Broken Arrow were on the previous day. The free-air winds at due West were from an easterly quarter with the same clockwise turning through S. to SW. as obtained at the two stations first discussed. The high clouds at this station, as also in Texas and Oklahoma, were moving from a southerly quarter. (See footnotes of Table 1.)

A small inversion of temperature is apparent at Due West between surface and 750 m. and a steady decrease from that level to the top of the flight. The decrease between 2,000 and 2,500 m. as the winds shift from SSE. to S. is rather pronounced.

The precipitation at Royal Center, Ind., owing to the high latitude of the station, was in the form of snow rather than rain. Easterly winds with a snowstorm prevailed at that station and the flight was not a high one.

The clockwise shift of the wind at Royal Center suggests that at that station, although at a great distance from the cyclone center the winds at higher elevations than those recorded must have been from a southerly quarter.

The barometric situation on the 8th and 9th compared.—The outstanding feature of the map of the 8th (fig. 1) is the ridge of high pressure that extends from Canada southeastward to Florida and the accompanying thrust of cold northwest winds. This ridge lying athwart the path of the New Mexico cyclone threatens the existence of the latter. Apparently, however, the danger to the New Mexico cyclone was not in the eastern ridge of high pressure but in the more direct and vigorous thrust of cold northerly air in its rear which reached the Gulf of Mexico by the morning of the 9th. The situation is now completely changed and the conditions for very generous and widespread precipitation in the great central valleys and Atlantic Coast States are almost ideal, viz, a trough of low pressure between two ridges of high pressure. From its position on the 9th the cyclone advanced northeastward, reaching the Delaware Capes on the 11th as a circular depression with central pressure of 29.00 inches. Heavy snow for the season fell in the Middle Atlantic and New England States.

The data here presented, and other evidence of a similar character, seem to indicate that for the continent of North America, at least, the southerly winds on the front of the cyclone, generally much stratified as to temperature, and the northerly winds in its rear, less stratified than those first mentioned, are the two most impressive phenomena in connection with cyclonic activity. These two major currents are not to be considered as opposing currents, but rather as currents one of which regularly supplants the other in practically the same levels.

The time required for the completion of the cycle warm–cold is short, a day or so, and it evidently bears a direct relation to the cycle, cyclone–anticyclone, which of course varies with the season and the latitude.

Each system of warm southerly winds must, of course, have two border zones, one on the left and one on the right as one faces toward the south. The movement of the air in the vertical on the right margin is pretty clearly established as an underrunning of the warm by the cold northerly current. The movement in the vertical on the left margin is not so clearly indicated; in the opinion of the writer the locus of cyclonic activity will be found nearer the left margin than the right.

In some respects these two wind systems, as conceived by the writer, are similar to the warm and cold currents postulated by the Norwegian school of meteorologists, although the details differ in several particulars. The generous cooperation of the Aerological Division of the bureau in the preparation of this paper is gratefully acknowledged.

THE SLEET, GLAZE, SNOW, AND WINDSTORM IN WISCONSIN, FEBRUARY 3-6, 1924

By W. P. STEWART, Meteorologist

(Weather Bureau, Milwaukee, Wis., March 29, 1924)

This storm occurred in connection with a marked area of low pressure which came up the Mississippi Valley on February 3 and 4 and passed slowly northeastward over Illinois, Indiana, and Michigan on the 5th and 6th. Southern and eastern Wisconsin were within the area of precipitation from February 3 until the morning of the 7th, and during that period heavy snows occurred over the greater part of this section. It was heaviest near Lake Michigan. At Milwaukee the heaviest 24-hour snowfall of record, 20.3 inches, occurred on the 4th–5th, and the total fall in the storm was 22 inches. At Manitowoc there was 25.5 inches, at Sheboygan 18 inches, at Port Washington 16 inches, at Racine 17 inches, at Sturgeon Bay 15 inches, and over a large part of central and southern Wisconsin the fall was from 10 to 12 inches.

There was a high east and northeast wind on the 3d, 4th, and 5th, and the snow drifted badly. Railway and interurban traffic was delayed 1 to 3 days. The most serious interruption to train service occurred in the territory north of Milwaukee, on the routes along the lake shore and in the vicinity of Fond du Lac and Oshkosh, where the schedules were interrupted from the night of the 4th until the afternoon of the 6th, and service was not fully restored until the 8th. Between Milwaukee and Chicago the service was interrupted from 9 p. m. the 4th until the afternoon of the 5th.

There were many miles of snowdrifts 8 to 12 feet high and highway traffic was blocked generally throughout the

area affected. This condition improved very slowly; some highways were not opened to traffic until the end of February. In the vicinity of Sheboygan automobiles were not able to get through until the last week in March.

The interests most seriously affected by the storm, however, were the overhead wire companies. In southern and southeastern Wisconsin the precipitation began on February 3 as a light misting rain which turned to sleet and snow during the night, the temperature being slightly below the freezing point. All exposed objects were covered with glaze. In Milwaukee the coating of ice averaged about $\frac{3}{16}$ inch in thickness, but the telegraph and telephone companies report that at some other points the coating of ice on wires was $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter. This ice together with the high winds caused the breakage of large numbers of telegraph and telephone poles and the prostration of many miles of wire. One company alone reported 924 poles broken, 480 miles of wire destroyed, 11,000 wire breaks, and 3,800 miles of wire to be repulled and retied to insulators. Their monetary loss was $172,000.

Because of broken wires, etc., the toll-line circuits of the telephone companies began to fail soon after midnight February 3–4, and most of them were out of order by 7 a. m. the 4th. Over most of these lines service was restored by the afternoon of the 9th, but in several localities it was interrupted for 10 days, and one of the larger companies expected that permanent repairs would not be completed until May 1.

From all available data it is estimated that the actual property loss from the storm was approximately $231,000, but the economic loss from delayed traffic of all kinds was much greater.

TORNADO IN NORTH TEXAS ON APRIL 3, 1924 [1]

A tornado was observed in Denton County, Tex., near the village of Justin about 4 p. m. April 3, 1924. It moved thence in an east-southeast direction through the northeast corner of Dallas County, the northern end of the adjoining county of Kaufman and was last observed about a mile southwest of Edgewood in Van Zandt County, having traveled a distance of about 80 miles in four hours. The tornado passed over a thinly settled district and for a part of its course the funnel cloud was not in direct connection with the ground. One person was killed and 14 injured and property loss of about $40,000 was sustained.

The meteorological conditions at the Dallas Weather Bureau station, when the tornado passed to the eastward about 12 miles directly north of the station, were not unusual or striking in any respect. The barometer fell from 29.88 inches at 8 a. m. 75th meridian time to 29.72 inches at 5:45 p. m. and then rose sharply 0.03 inch.

Hail fell in the path of the tornado in Denton, Rockwall, and Dallas Counties. There was but little thunder and lightning. The width of the tornado's path was about 1,000 feet and that of the hail fall from $\frac{1}{2}$ to 2 miles.

The usual number of freaks, such as straws being driven into wood, etc., were observed.

[1] Condensed from a report by J. L. Cline, Meteorologist, Weather Bureau Office, Dallas, Tex.

NOTE ON PARTIAL CORRELATION [1]

By EDGAR W. WOOLARD

At the time that Doctor Walker commenced his researches on seasonal correlations [2], the modern form of the theory of multiple linear correlation was new [3], and in large part he developed his own notation and methods. Walker's method of deriving the total correlation coefficient and the regression equation differs from that expounded in the textbooks of statistics, yet it apparently entails less arithmetical labor, and should be more widely known than it is.

If a variable quantity X_1 depends upon a number of other variable quantities $X_2, X_3, \ldots X_k$, then we may look upon the successive variations of X_1 from its arithmetic mean as made up of (1) portions due to the variations of X_2 from its arithmetic mean, and (2) remainders, independent of X_2, due to the variations in $X_3 \ldots X_k$, and more or less of the nature of accidental errors. Under these circumstances, if we assume a linear relation between the variations x_1 from the mean of X_1 and the variations x_2 from the mean of X_2, the Theory of Least Squares gives for the "best" representation of the relationship.

$$x_1 = r\frac{\sigma_1}{\sigma_2}x_2 \tag{1}$$

in which the so-called correlation coefficient

$$r = \frac{\Sigma(x_1x_2)}{N\sigma_1\sigma_2} \tag{2}$$

expresses the proportionate extent to which the variations in X_1 are determined by, or related to, those of X_2. Similarly, if we wish to determine the extent to which the variations in X_1 are due to those in $X_2, X_3, \cdots X_n$ jointly, exclusive of the effects of $X_{n+1}, X_{n+2}, \cdots$, we have, assuming a linear relation

$$x_1 = a_{12}x_2 + a_{13}x_3 + \cdots + a_{1n}x_n, \tag{3}$$

where, in the case of four variables for example, as Walker has shown

$$a_{12} = \frac{\sigma_1\{r_{12}(1-r^2_{34}) + r_{13}(r_{24}r_{34} - r_{23}) + r_{14}(r_{23}r_{34} - r_{24})\}}{\sigma_2\{1 - r^2_{23} - r^2_{24} - r^2_{34} + 2r_{23}r_{24}r_{34}\}}, \text{etc.}, \tag{4}$$

while the "effective correlation coefficient" is

$$m = \frac{1}{\sigma_1}\sqrt{[a_{12}\sigma_2 r_{12}\sigma_1 + a_{13}\sigma_3 r_{13}\sigma_1 + a_{14}\sigma_4 r_{14}\sigma_1]}, \tag{5}$$

and expresses the proportionate extent to which the variations in X_1 are governed by those in X_2, X_3, X_4.

[1] Presented as part of the discussion on Dr. G. T. Walker's method of making monsoon rain forecasts, Weather Bureau staff meeting of Apr. 16, 1924.

[2] G. T. Walker. Correlations in Seasonal Variations of Climate. *Mem. Ind. Metl. Dept.*, Vol. XX, pt. 6, 1909; Correlation in Seasonal Variations of Weather, II, *Mem. Ind. Metl. Dept.*, XXI, pt. 2, 1910; III, XXI, 9, 1914; IV, XXI, 10, 1915; V, XXI, 11, 1915; VI, XXI, 12, 1915; VII, XXIII, 2, 1922; VIII, XXIV, 4, 1923.

[3] G. U. Yule. On the Theory of Correlation for any Number of Variables, Treated by a new System of Notation. *Proc. Roy. Soc.*, A79, 182–193, 1907.

Now, in the form in which the theory has been developed by Pearson and Yule, the "total correlation coefficient," showing the combined effect of all the factors upon X_1, is

$$R_{1.234 \cdots n} = \sqrt{[1-(1-r^2_{12})(1-r^2_{13.2})(1-r^2_{14.23}) \cdots (1-r^2_{1n.234 \cdots (n-1)})]} \quad (6)$$

in which

$$r_{12.34 \cdots i} = \frac{r_{12.34 \cdots (i-1)} - (r_{1i.34 \cdots (i-1)})(r_{2i.34 \cdots (i-1)})}{\sqrt{1-(r^2_{1i.34 \cdots (i-1)})(1-r^2_{2i.34 \cdots (i-1)})}} \quad (7)$$

is the net coefficient of correlation between X_1 and X_2 after the effects of X_3, ... X_i have been eliminated. The regression equation (3) becomes

$$x_1 = b_{12.34 \cdots n} x_2 + b_{13.24 \cdots n} x_3 + \cdots + b_{1n.23 \cdots (n-1)} x_n, \quad (8)$$

where

$$b_{12.34 \cdots n} = r_{12.34 \cdots n} \frac{\sigma_{1.34 \cdots n}}{\sigma_{2.34 \cdots n}}, \text{ etc.,} \quad (9)$$

$$\sigma_{1.34 \cdots n} = \sigma_1 \sqrt{(1-r^2_{13})(1-r^2_{14.3}) \cdots (1-r^2_{1n.34 \cdots (n-1)})}. \quad (10)$$

Walker has shown the identity of his m and Yule's $R_{1.234 \cdots n}$; and it is not difficult to show that the numerical values of the coefficients given by (4) and (9) are identical, but are much more easily obtained by the following device due to Walker:

Write (3) in the form

$$\frac{x_1}{\sigma_1} = c_2 \frac{x_2}{\sigma_2} + c_3 \frac{x_3}{\sigma_3} + \cdots + c_n \frac{x_n}{\sigma} \quad (11)$$

by replacing a_{1i} with $c_i \frac{\sigma_1}{\sigma_i}$; the ratios of the actual departures from the averages to the standard deviations, x_i/σ_i, Walker calls the "proportional departures." Then it may be shown that

$$m^2 = c_2^2 + c_3^2 + c_4^2 + \cdots + c_n^2 + 2c_2c_3r_{23} + 2c_2c_4r_{24} + \cdots + 2c_3c_4r_{34} + \cdots . \quad (12)$$

Furthermore, since

$$x_i = r_{ij} \frac{\sigma_i}{\sigma_j} x_j, \quad (13)$$

we have

$$\begin{aligned} r_{12} &= c_2r_{22} + c_3r_{23} + c_4r_{24} + \cdots + c_nr_{2n}, \\ r_{13} &= c_2r_{23} + c_3r_{33} + c_4r_{34} + \cdots \; c_nr_{3n}, \\ &\cdots\cdots\cdots\cdots \\ r_{1n} &= c_2r_{2n} + c_3r_{3n} + c_4r_{4n} + \cdots + c_nr_{nn}, \end{aligned} \quad (14)$$

$(n-1)$ simultaneous linear equations from which the c's may be found, by employing any of the well known shortened methods of solving such a set of equations.[4]

Thus the total correlation coefficient and the regression equation may be found without computing any of the great number of net correlations required by the usual methods.

[4] See E. T. Whittaker and G. Robinson. *The Calculus of Observations*, London, 1924. Chap. V, and *Arts*, 121, 117.

NOTES, ABSTRACTS, AND REVIEWS

FOUR WIRELESS STATIONS TO BE ERECTED IN GREENLAND

(Excerpts from report by J. D. Price, United States minister, Copenhagen, Denmark, March 10, 1924)

The parliamentary committee on finance has now granted an appropriation of about 700,000 crowns [$170,327.00] for the erection of four wireless stations (of the Danish Poulsen system) on Greenland, which Continent will thus be enabled to share directly in world intercourse. The stations are also expected to prove of both direct and indirect value to commerce and science, especially to the international weather service.

The stations, which are to be constructed by the Danish Radio Co. of Danish material supplied by Skoumann & Petersen and other Danish firms, are to be located at Angmagsalik (on the eastern coast), Julianehaab (southern point of Cape Farewell), Godhavn and Godthaab (both on the western coast). The main station is to be at Julianehaab and is to be of sufficient capacity under normal conditions to correspond with the present stations at Reykjavik (Iceland) and Thorshavn (Faeroes), and under especially favorable conditions, to reach the main Danish station at Lyngby (near Copenhagen) and the European Continent.

Three of the stations are to be adapted for telegraphic communication with continuous waves, and to be fitted with spark transmitters for local correspondence.

FRANK HAGAR BIGELOW, 1851-1924

Professor Bigelow was born at Concord, Mass., of sturdy New England antislavery stock. He was graduated from Harvard in the class of 1873, and soon thereafter entered the Episcopal ministry. The development of an affection of the lungs cut short his ministerial career, although he was in close affiliation with the church throughout his whole life. In seeking a dry climate his attention was directed to Argentina where a former Harvard graduate, the late Dr. B. A. Gould, was engaged in astronomical work. Bigelow served as assistant to Doctor Gould, 1873–1876 and again 1881–1883. Returning from South America he was successively professor of mathematics, Racine College, 1884–1889 and assistant in the Nautical Almanac Office, 1889–1891, member of United States Eclipse expeditions, to West Africa, 1889; Newberry, S. C., 1900; Spain, 1905. He was appointed professor of meteorology in the United States Weather Bureau in October, 1891, and resigned in 1910. He spent the next 11 years with the meteorological service of Argentina, being stationed for the most part at Cordoba and Pilar. On his retirement from that service in 1921 he went first to Marseilles, France, and later to London. Finally, he went to Vienna where he died of pneumonia on March 2, 1924. His wife survived him but a few days and succumbed to the same disease

Professor Bigelow was by nature a student-investigator and was possessed of a seemingly inexhaustible supply of energy backed by the will to pursue any subject that he might take up until the end.

Perhaps his outstanding piece of work while with the Weather Bureau was his contribution to the subject of the general circulation of the atmosphere in a series of related papers that were published in the MONTHLY WEATHER REVIEW, 1902–1906. Previous to the writing of these papers he had finished two ponderous volumes, the first on the international cloud observations, and the second on the barometry of the United States. Both

publications appeared as the second volume of the Report of the Chief of Weather Bureau, for the years, 1899-1900 and 1900-1901, respectively. His last important piece of work while with the Weather Bureau was an investigation of the evaporation of Salton Sea, a body of water that filled a depression in southeastern California by overflow from the Colorado River.

In 1904 Professor Bigelow advocated a very elaborate project for a scientific organization in the Weather Bureau for research and investigation into atmospheric, electrical, and magnetic phenomena and their correlation with solar characteristics. This was partly carried into effect in the institution known as Mount Weather, but his connection with the bureau was severed without his ambitions in this connection being attained. The present writer was closely associated with Professor Bigelow during the latter's service in the bureau.

Personally, he was reserved and was not what is commonly called a "good mixer."

Owing to the highly mathematical and often obscure character of his papers the leading officials of the Weather Bureau found it difficult to follow the force of his arguments or concur in the integrity of his conclusions. This led to a sort of isolation of the author, which fact Bigelow no doubt felt rather keenly at times. Indeed, discouragement at the outlook probably was an important factor in the termination of his connection with the bureau.

As his investigations into the general circulation of the atmosphere progressed he found himself departing more and more widely from the views held by Ferrel and other early writers. Before he left the Weather Bureau in 1910, the idea of entirely revamping meteorology had taken possession of him, at first as a mild sort of obsession, which later became the impelling object of his existence. With the infirmities of age bearing upon him and not meeting with the responses that he thought were due his labors, it is not strange that his occasional letters to his old associates were tinged with more or less bitterness against those who withheld their approval of his radical views and system.

He published in New York in 1915 a treatise on Circulation and Radiation in the atmospheres of the earth and of the air. While this publication apparently presented his final views he followed it by supplements, of which 5 were issued, the final supplement, No. 5 of the series, bears the following suggestive title: "The New Must Replace the Old, Delenda est Carthago, Atmospheric Physics as Applied to a Reformed Meteorology."

One can not but admire the indomitable spirit of the man, doubtless inherited from his militant New England ancestors. Like the martyrs of old he went down with his colors flying. Broken by the infirmities of age, and in a foreign land his last communication to the Weather Bureau, couched in the same spirit as the earlier ones, was dated Vienna, February 21. Ten days later he passed away. His remains, together with those of his wife, were brought to this country and interred at Concord, Mass., his birthplace, on April 12, 1924.—*A. J. Henry.*

BORIS WEINBERG APPOINTED DIRECTOR

Announcement has recently been received of the appointment on January 30, 1924, of Prof. Boris Weinberg as the new director of the Central Physical Observatory at Leningrad (formerly Petrograd).

WEATHER BUREAU STAFF MEETINGS[1]

Following is a continuation of the program of the Weather Bureau staff meetings:

MARCH 5, 1924

C. F. Marvin: The Sun Spot period in terrestrial temperatures.

MARCH 19, 1924

C. P. Olivier: Professor of astronomy in the Leander McCormick Observatory, University of Virginia (by invitation): Meteors.

APRIL 2, 1924

E. H. Bowie: Diagnosing synoptic weather charts.

APRIL 16, 1924

A. J. Henry: Seasonal forecasting in India (based on the work of Dr. Gilbert T. Walker).

MAY 7, 1924

S. P. Fergusson: An improved anemometer for general use.

P. C. Day: Difficulties in reducing wind velocities to a uniform standard.

MAY 22, 1924

E. H. Bowie: The problem of the daily weather map. A suggested solution.

With this meeting the series closes until autumn of 1924.—A. J. H.

[1] Cf. this REVIEW, 52: 35-36.

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Sondatges de l'atmòsfera lliure a Barcelona, amb globus pilots, des del 1. er de Juliol al 31 de Desembre de 1923. Barcelona. 1924. 32 p. 21½ cm. (Servei met. de Catalunya. Notes d'estudi. N.° 28.)

Braak, C.

Het klimaat van Nederlandsch-Indie. v. 1. pt. 4. Batavia. 1923. v. p. plates (part fold.) 27½ cm. [K. Mag. en met. obs. Batavia. Verh. 8.] [With English summaries.]

Burns, George P.

Studies in tolerance of New England forest trees. no. 4. Minimum light requirement referred to a definite standard. Burlington. 1923. 32 p. figs. plates. 23 cm. (Vt. agric. exp. sta., July, 1923. Bulletin 235.)

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Climate of Nanking. [18 p.] 25½ cm. [Title and text in Chinese.]

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Le divisioni dell' anno a seconda dei fenomeni meteorologici. 6 p. 27½ cm. [Estr.: Boll. bimen. Soc. met. ital., N. 1-3, Gen.-Marzo 1924.]

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Observacions pluviomètriques de la Xarxa Catalana, corresponents als anys 1911, 1912, 1913, 1918, 1919 i 1920. Barcelona. 1924. 56 p. maps. 21½ cm. (Servei met. de Catalunya. Notes d'estudi. N.° 27.)

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Variation in annual run-off in the Rocky Mountain region. Washington. 1923. 14 p. figs. plates (fold.) 23 cm. (U. S. Geol. survey. Water-supply paper 520–A.)

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Radiogrammes météorologiques émis par les postes T. S. F. régionaux français. Correctif No 20 de la notice No 11,637 du 19 octobre 1922. En vigueur au 10 mars 1924. [Paris.] 1924. 24 p. 31 cm. [Manifolded.]

Haushofer, Karl.
Die Einheit der Monsunländer. p. 20–27. 24 cm. [Exc.: Zeits. für Geopolitik. Jahrg. 1, Jan., 1924.]

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Medical climatology of England and Wales. London. 1923. xiv, 302 p. plates. 22 cm.

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Messmethoden der atmosphärischen Elektrizität. p. 451–482. illus. 25½ cm. [In Abderhalden, Emil, *ed.*, Handbuch der biologischen Arbeitsmethoden. Abt. 2, Physikalische Methoden, Heft 3.]
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Determination of daylight intensity at a window opening. 18 p. figs. 23 cm. [Trans. Illum. engin. soc., v. 19, no. 3, March 1924.] [Preprint.]

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Die Klimate der Erde. Grundriss der Klimakunde. Berlin. 1923. x, 369 p. illus. plates (part fold.) 20½ cm.

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Annual report. 13th. 1923. Albany. 1924. 254 p. illus. front. map (fold.). 23 cm. [Describes experiments with balloons to study spread of gypsy moth by the wind, p. 162–169.]

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The balance of precipitation and evaporation by land and sea. p. 6–8. (Feb.)
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SOLAR OBSERVATIONS

SOLAR AND SKY RADIATION MEASUREMENTS DURING MARCH, 1924

By HERBERT H. KIMBALL, In Charge, Solar Radiation Investigations

For a description of instruments and exposures and an account of the method of obtaining and reducing the measurements, the reader is referred to the REVIEW for January, and February, 1924 **53**:42 and 113.

From Table 1 it is seen that solar radiation intensities averaged slightly below normal values for March at all three stations.

Table 2 shows that the total solar and sky radiation received on a horizontal surface averaged slightly above normal at Washington and below normal at Madison and Lincoln.

Skylight-polarization measurements made on six days at Washington give a mean of 55 per cent with a maximum of 63 per cent on the 24th. These are slightly below the average March values. At Madison no measurements were obtained as the ground was covered with snow throughout the month.

TABLE 1.—*Solar radiation intensities during March, 1924*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	8 a.m.	Sun's zenith distance 78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	[1]1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Mar. 3	3.15				1.02						3.81
4	3.81		0.54	0.69	0.90						4.57
6	4.17			0.91							3.63
12	3.63					1.50	1.28				3.45
13	2.36	0.81	0.93	1.09	1.23		0.95				2.87
17	2.36		0.87	0.98	1.17	1.39					2.87
19	3.81		0.70	0.90	1.21		0.96				3.00
22	4.57			1.03	1.18	1.36					4.17
24	4.17			1.04	1.24	1.53					6.50
28	3.99		0.70	0.84	1.09	1.41					3.99
31	3.30	0.59	0.73	0.90	1.11	1.36	1.04				3.45
Means		**(0.70)**	**0.74**	**0.93**	**1.13**	**1.42**	**1.06**				
Departures		**−0.01**	**−0.07**	**−0.01**	**−0.02**	**±0.00**	**−0.05**				

TABLE 1.—*Solar radiation intensities during March, 1924*—Contd

Madison, Wisconsin

Date	8 a.m.	Sun's zenith distance 78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	[1]1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Mar. 5	2.26		1.02	1.13	1.30						2.74
13	2.95				1.30						3.30
14	1.78				1.37						2.16
15	1.45				1.32	1.54					2.62
18	3.00						1.31	1.16			3.30
27	4.57						1.26				6.76
Means			**(1.02)**	**(1.13)**	**1.32**		**(1.28)**	**(1.16)**			
Departures			**−0.02**	**−0.06**	**±0.00**		**−0.03**	**±0.00**			

Lincoln, Nebr.

Date	8 a.m.	5.0	4.0	3.0	2.0	[1]1.0	2.0	3.0	4.0	5.0	Noon
Mar. 6	2.87	1.02			1.38	1.53					2.36
11	2.36		0.97	1.13	1.32	1.52	1.32	1.13	0.96	0.84	2.62
21	3.45			0.98	1.20	1.51	1.19	0.92			3.99
26	3.81		0.91	1.11	1.29	1.49	1.30	1.14	0.99		4.95
27	4.17		0.87	1.08	1.18		1.20	0.99	0.83		7.57
Means		**(1.02)**	**0.92**	**1.08**	**1.27**		**1.25**	**1.04**	**0.93**	**(0.84)**	
Departures		**+0.14**	**−0.01**	**±0.00**	**−0.02**		**−0.02**	**−0.03**	**+0.01**	**+0.05**	

[1] Extrapolated

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

Week beginning—	Average daily radiation				Average daily departure for the week			Excess or deficiency since first of year		
	Chicago	Washington	Madison	Lincoln	Washington	Madison	Lincoln	Washington	Madison	Lincoln
	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Feb. 26	158	290	224	334	+8	−60	−9	+643	−1,329	−379
Mar. 5	124	228	286	372	−82	−23	+4	+68	−1,488	−351
12	200	483	372	288	+143	+46	−106	+1,072	−1,169	−1,095
19	197	376	228	377	+15	−117	−38	+1,179	−1,985	−1,359
26	153	314	296	443	−63	−66	+14	+735	−2,445	−1,261

WEATHER OF NORTH AMERICA AND ADJACENT OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

The following table shows the average pressure for the month at a number of land stations on the coast and islands of the North Atlantic. The readings are for 8 a. m., 75th meridian time, and the departures are only approximate, as the normals were taken from the Pilot Chart and are based on Greenwich mean noon observations, which correspond to 7 a. m., 75th meridian time.

Station	Average pressure	Departure
	Inches	*Inches*
St. Johns, Newfoundland	29.48	−0.36
Nantucket	29.71	−0.29
Hatteras	29.85	−0.17
Key West	29.97	−0.05
New Orleans	29.98	−0.04
Swan Island	29.87	−0.12
Turks Island	30.02	±0.00
Bermuda	29.84	−0.20
Horta, Azores	29.65	−0.49
Lerwick, Shetland Islands	29.84	+0.13
Valencia, Ireland	29.78	−0.12
London	29.89	−0.07

It will be noticed that the average pressure at Horta, Azores, was very much below the normal for March; the barometer at that station read above 30 inches only on the 1st and the 28th to 31st, while the lowest reading, 29.20 inches, occurred on the 9th. During the greater part of the month the North Atlantic HIGH was conspicuous by its absence, and the persistent intrusion of low pressure over the region usually occupied by this so-called center of action was responsible for abnormal weather conditions over a large section of the ocean.

Judging from reports received, the number of days on which winds of gale force were reported over the greater part of the steamer lanes was not far from the normal as shown on the Pilot Chart. Over the western section of the ocean and in southern waters, west of the Azores, gales were unusually prevalent, while east of the 25th meridian comparatively moderate weather was the rule.

The number of days with fog was apparently less than usual over the Grand Banks, and about normal in the vicinity of the European and American coasts. A most

remarkable feature was the prevalence of fog in the Gulf of Mexico where it was observed on nine days.

On the 1st and 2d there occurred the only well-developed and severe disturbance in the immediate vicinity of the British Isles, and on the latter date moderate to strong gales were reported from a limited area between the 45th and 60th parallels. Storm log:

British S. S. *New York City.*

Gale began on February 29th, wind WNW. Lowest barometer 28.87 inches at 8 a. m. on the 2d, wind WNW., 8, in latitude 50° 54′ N., longitude 15° W. End on the 2d, wind NNW. Highest force of wind 9, WNW.; shifts WNW.–NW.–N.

From the 3d to the 7th the region between the Azores and Bermudas was covered by an area of low pressure, and during this period heavy weather was reported by a number of vessels between the 30th and 45th parallels. storm log:

American S. S. *Coelleda:*

Gale began on the 3d, wind NW. Lowest barometer 29.74 inches at 4 p. m. on the 3d, wind NW. 7, in latitude 38° 22′ N., longitude 65° W. End on the 6th, wind NW. Highest force of wind, 9, NW.; steady NW.

On the 8th a LOW was central near latitude 42° N., longitude 62° W.; its progress is shown on Maps VIII to XIII, which cover the period from the 9th to 14th, inclusive, when especially heavy weather prevailed over a large part of the ocean. Storm logs:

American S. S. *West Haven:*

Gale began on the 7th, wind NW. Lowest barometer 29.47 inches at 4 a. m. on the 9th, wind NW., 9, in latitude 38° 19′ N., longitude 66° 54′ W. End on the 10th, wind NNW. Highest force of wind 11; steady NW.

American S. S. *Radiant:*

Gale began on the 10th, wind SE. Lowest barometer 29.23 inches at 7 a. m. on the 10th, wind SE., 6, in latitude 33° 40′ N., longitude 75° 30′ W. End on the 12th, wind NW. Highest force of wind 11; shifts SE.–WNW.

American S. S. *Collingsworth:*

Gale began on the 11th, wind W. Lowest barometer 29.64 inches at 10 a. m. on the 11th, wind W., 7, in latitude 26° 23′ N., longitude 70° 22′ W. End on the 13th, wind WNW. Highest force of wind 10; shifts SW.–W.

American S. S. *F. H. Hillman:*

Gale began on the 13th, wind SSW. Lowest barometer 29.61 inches at 10 a. m. on the 13th, wind SW., 8, in latitude 29° 10′ N., longitude 48° 15′ W. End on the 15th, wind WSW. Highest force of wind, 10 WNW.; shifts SW.–WSW.

From the 15th to the 19th there was a well-developed LOW in the vicinity of Newfoundland, that moved but little during this period, and a number of vessels between the 40th meridian and the American coast encountered moderate to strong gales, accompanied by hail and snow.

Charts XIV and XV show the conditions on the 21st and 22d, respectively, when a severe disturbance prevailed between the Bermudas and Hatteras that is described elsewhere in the REVIEW. These maps also show a second and much deeper depression northwest of the Azores, which was attended by moderate to strong gales. Storm log:

British S. S. *Maryland:*

Gale began on the 22d. Lowest barometer 28.42 inches at 3 p. m. on the 22d, wind SSE., in latitude 46° 28′ N., longitude 32° 40′ W. End at midnight on the 22d, wind NNW. Highest force of wind 9; shifts SSE.–NNW.

By the 23d the western LOW was central near latitude 40° N., longitude 45° W., while the second depression was somewhere between the 30th meridian and the coast of Great Britain. Storm log:

American S. S. *Balsam:*

Gale began on the 22d, wind NE. Lowest barometer 29.31 inches at noon on the 22d, wind NE., 7, in latitude 39° 44′ N., longitude 60° 46′ W. End on the 25th, wind NE., 9. Highest force of wind 9, NE.; shifts NE.–N.–NE.

On the 27th there was a disturbance central about 200 miles south of Halifax and moderate to strong gales prevailed as far south as the Bermudas; by the 28th it was over Newfoundland, while the storm area had contracted considerably in extent. Storm log:

British S. S. *Maryland:*

Gale began on the 27th, wind SW. Lowest barometer 29.11 inches at 6 p. m. on the 27th, wind W., in latitude 40° 59′ N., longitude 63° 30′ W. End on the 28th, wind WNW. Highest force of wind 10, WNW.; shifts W.–WNW.

On the 29th Hatteras was in the southeastern quadrant of a LOW that moved east-northeastward, and on the 30th was central a short distance southeast of Nantucket, while by the 31st it was near St. Johns, Newfoundland. Storm log:

Italian S. S. *Posillipo:*

Gale began on the 29th, wind SW. Lowest barometer 29.68 inches at 12:30 a. m. on the 29th, wind SW., 9, in latitude 37° N., longitude 66° 05′ W. End on the 30th, wind WNW. Highest force of wind 10, SW.; shifts SW.–WNW.

On the 30th there was a second disturbance near latitude 48° N., longitude 45° W., that moved rapidly eastward and by the 31st was in the vicinity of latitude 50° N., longitude 35° W. Storm log:

Belgian S. S. *Menapier;*

Gale began on the 30th, wind SSE., 3. Lowest barometer 29.75 inches at 5 a. m. on the 30th, wind S., 11, in latitude 44° 44′ N., longitude 37° 37′ W. End on the 31st, wind W. Highest force of wind 11, SSW.; shifts S.–SSW.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Fine weather prevailed over most of the middle latitudes of the north Pacific Ocean during March, so that vessels following the central and southern routes as a rule experienced smooth sailing. Neither was the weather altogether rough and disagreeable along the northern routes, although gales occurred daily over some portion of the upper waters of the sea.

One factor which contributed largely to the generally settled weather over the eastern part of the ocean was the permanence of the great high-pressure area bridging Hawaii and the American coast. During several preceding months this anticyclone had been frequently and seriously disturbed, but in March it persisted with scarcely a break throughout the month, only fluctuating somewhat with the changing conditions surrounding it.

Hawaii experienced nearly normal weather, except that the rainfall was considerably deficient. The wind velocity averaged 9.4 miles an hour, and maximum velocities exceeded 25 miles per hour on six days, the highest being 34 miles from the east on the 1st. The trades were very steady in this region, and there were few departures from easterly and northeasterly directions. These departures were generally on the 21st to 24th during the prevalence of a depression to the eastward and northward of Midway Island. A slight disturbance appeared to the northeastward of Hawaii on the 28th to 30th, but no gales were reported from it.

Naturally the greater number of storm winds resulted from the activities of the Aleutian LOW. This cyclone was well developed during the first two decades of March, though oscillating north and south and east and west over a considerable area. The average center was nearly over or to the westward of Dutch Harbor. From

the 21st to the 27th more high than low pressure covered this region and Alaska, while cyclone centers ran in lower latitudes than they had earlier in the month. By the close of March, however, the Aleutian LOW had once more developed and was central over Bering Sea.

The marked low pressure which set in at Dutch Harbor on February 17, as noted in the review of the weather of that month, continued almost without interruption until March 21. The average daily departure for the first 20 days of the month was −0.45 inch. Moderately high pressure then prevailed until the 30th. The average daily pressure for the month (28 days), based on p. m. observations, was 29.48 inches. The normal is 29.77. The highest pressure reported was 30.36, occurring on the 22d; the lowest, 28.80, on the 10th. Absolute range, 1.56 inches. At Midway Island pressure was somewhat above normal during the first two decades and below during the last decade. The average for the month (29 days) was 30.06 inches; normal, 30.10. The highest reading, 30.16, was recorded on the 9th and 13th; the lowest, 29.88, on the 20th and 22d. At Honolulu pressure was above normal from the 1st to the 14th and from the 25th to the 30th. The average for the month (p. m. observations) was 30.06; normal, 30.04. The highest reading, 30.19, was recorded on the 12th; the lowest 29.91, on the 20th.

The high-pressure area overlying the China coast during the greater part of the month caused a quite steady monsoon current that at times increased to gale strength down the Formosa Channel and to the eastward of Taiwan.

Several Manchurian cyclones crossed Japan, and on the night of the 21st–22d hurricane velocities were recorded by the American S. S. *Ensley City* southeast of Yokohama, during the passage of one of these storms.

In tropical waters, both east and west, no disturbances seem to have figured this month. And no gales have been reported by vessels crossing even that place of winds, the Gulf of Tehuantepec, off the south coast of Mexico.

The periods of greatest storm violence over the sea area were those of the 5th to the 10th, 13th to 15th, and the 21st to the 23d. These dates are those on which wind velocities of force 11 or 12 were recorded by ships' observers.

The most troubled region generally was in mid-ocean to the southward of the central Aleutians, but hurricane winds occurred also far to the westward. Forces of 9 or 10 were noted on several dates on which higher velocities did not occur, and these were the strongest winds reported from the eastern high pressure area, as well as from the Gulf of Alaska.

On the 3d and 4th, while the Aleutian LOW was farthest eastward, the American S. S. *Stockton*, bound for Portland, Oreg., while near 50° N., and running between 145° and 138° W., encountered gales of force 10 coming from south-southwest to south-southeast, and observed a minimum pressure of 29.35 inches.

On the 5th a cyclone of moderate energy entered upon the ocean from Japan. It caused gales along the coast on the 5th and 6th and to the northward of the Bonin Islands on the 7th. On the 7th, 8th, and 9th, with the eastward passage of this storm, now intensified, whole gales to hurricane winds swept over an area extending roughly between latitudes 40° and 50° N., longitudes 150° E. and 175° W.

The American S. S. *Ethan Allen*, bound from Manila toward San Pedro, Calif., entered the southern influence of this cyclone, or storm belt, on the 6th, when near 44° N., 170° E. Pressure fell constantly throughout the 7th, and from 10 a. m. until after 6 p. m. the winds attained force 10 to a full hurricane. The lowest pressure, 28.16 inches, was read between midnight of the 7th and 2 a. m. of the 8th, while the vessel was in the midst of light east-southeasterly winds, and probably near the center of the disturbance, in latitude 44° 36′ N., longitude 175° 12′ E. This reading of the barometer is the lowest thus far recorded for the month. Storm winds, with few interruptions, were experienced by the *Ethan Allen* until mid-afternoon of the 8th, and pressures approximating 29 inches or below were observed on board the vessel until the morning of the 9th, when she was near 45° N., 173° W.

There were other vessels experiencing the violence of this general storm area. The Canadian S. S. *City of Vancouver* was hove to from "7.50 p. m. of the 7th until noon of the 8th, during which time the engines were going slow astern." During this period she was near 46° 36′ N., 178° to 179° E., experiencing southeasterly to southwesterly winds, force 9 to 10, lowest pressure 28.63 inches.

On the 8th and 9th the British S. S. *Benmacdhui*, Portland toward Shanghai, Capt. T. J. Smith, met with very rough weather at or near 48° N., 165° E., lowest pressure 28.75. The observer, W. E. Barrett, second officer, noted:

8th. Wind increasing to gale force, backing to NW. by W., with squalls, force 11. Overcast, continuous sleet; rough, confused sea; westerly swell.

9th. Whole gale, decreasing to strong squalls, force 10; wind backing to SW. 8; very rough and confused sea; westerly swell. Decks covered with thick ice.

The British S. S. *Knockfierna*, westward bound, after crossing the area already mentioned, on the 7th and 8th, encountered whole gales to hurricane winds from north to northwest on the 9th, in 44° 30′ N., 157° 46′ E. The observed temperature at 10:30 p. m. of the 9th (local time) was 23° F., with heavy snow falling.

In west longitudes, during this general period, the American S. S. *Bessemer City* recorded the easternmost appearance of hurricane winds for the month. This was in 40° N., 159° W. The extreme velocity was of brief duration, and the lowest pressure observed was only 29.70 inches. On the 9th and 10th the same vessel experienced violent squalls, the extreme velocity of which attained force 12 on the 9th, in 34° 50′ N., 175° 30′ W., minimum barometer 29.77.

The American S. S. *West Jester* fell in with much foul weather on the 7th to 9th, after crossing the 180th meridian, eastward bound, near the 50th parallel. For two days the steamer was hove to, amidst high seas and long-continued gales of force 11 from southeast to east-northeast. Her lowest observed pressure was 28.71 inches, in 48° N., 179° W., on the 7th.

The British S. S. *Margaret Coughlan* observed a minimum pressure of 28.40 inches, highest wind force 10 E., in 51° 43′ N., 18°, 46′ W., on the 9th.

On March 13 a depression left the Japanese coast. It intensified at sea, and on the 14th and 15th caused whole gales far to the eastward. The highest wind velocity reported was 11 SW., by the American S. S. *India Arrow*, lowest pressure 29.22 inches, while in 40° N., 172° E.

On the 16th and 17th, while a LOW was central over eastern California and vicinity, with the north Pacific HIGH strongly crested at 45° N., 140° W., there was some considerable barometric gradient along the coast.

The American S. S. *Lurline*, shortly before entering San Francisco Harbor, ran into a northwest gale, force 10, pressure 29.68 inches.

On the 18th the American S. S. *Bakersfield* experienced a whole westerly gale, lowest pressure 28.81 inches, in 47° 16′ N., 178° 42′ E., and on the 22d the Japanese tanker *Kamoi*, Yokohama to San Pedro, met with a north-northeasterly hurricane in 45° N., 179° E., without much depression of the barometer.

During the remaining days of the month there was a slackening in storm intensity, although on the 25th and 26th whole westerly gales were reported from the southward of Dutch Harbor, the barometer on board the American S. S. *Norlina* registering a pressure as low as 28.51 inches, in 50° 13′ N., 167° 35′ W.

On the 30th whole gales also occurred to the westward of the 180th meridian, the Japanese S. S. *Boston Maru* reporting a southwesterly wind, force 10, in 49° 33′ N., 177° 07′ E. The lowest observed pressure on this date was 28.64 inches, read on board the American S. S. *West Jessup* during a strong northerly gale, in the midst of a driving snowstorm, in 46° 50′ N., 168° 12′ E.

There was some slight shifting in the fog area since February. Much less of the phenomenon was observed along the American coast, but there was a slight increase in its occurrence over the general region of the great eastern high pressure area. Scattered fog occurred thence along the northern routes to the 160th meridian of east longitude.

NOTE.—In the February weather review of the north Pacific Ocean the highest noted force of the wind for the month was given as 11. A late report received from the British S. S. *Knockfierna* shows that a full southeasterly hurricane was encountered on February 25, while the vessel was in latitude 52° 20′ N., longitude 154° 05′ W., the minimum pressure read being 28.45 inches.

GALES OFF THE AFRICAN COAST AND IN AUSTRALIAN WATERS

By ALBERT J. MCCURDY, JR.

Gales of short duration and limited extent prevailed off the north and east African coast throughout March, as indicated by weather reports from vessels traversing shipping routes in that region.

The American S. S. *Nile*, Capt. Charles Olsen, proceeding from Bombay to the United States, via Port Said, on the 4th, while in the Red Sea, encountered a moderate gale with rough seas. Mr. Christian Olsen, second officer, reports that the lowest pressure observed was 29.90 inches (uncorrected), occurring at 2:40 p. m., in 24° 03′ N., 36° 11′ E. The wind at this time was NNW., force 7.

On the 8th and 9th the British S. S. *Hyson*, Capt. A. S. Blues, proceeding from Singapore to Jeddak, experienced a moderate southerly gale and rough seas off the islands of Perim and Kamaran in the Red Sea. The second and third officers state that the lowest pressure, 29.76 inches (corrected), was observed off Kamaran Island at 2:51 p. m., on the 9th, at which time the wind was S., force 7.

The *Hyson* encountered its second gale of the month north of Port Said on the 16th, while proceeding from Jeddak to Algiers. The second officer reports a rough confused sea with occasional rain squalls. At 8 p. m., while in 33° 30′ N., 26° 23′ E., the lowest pressure was observed, 29.42 inches (corrected). The wind at this time was SSW., force 7, but later shifted to northwest and increased to a fresh gale. This gale continued until 4 p. m., on the 17th.

The British S. S. *Clan Malcolm*, Capt. C. J. Higgins, Calcutta toward London, was involved in the same storm from the 16th, when proceeding into the Suez Canal, until midnight of the 17th, reporting conditions similar to those experienced by the *Hyson*. The lowest pressure reading, 29.61 inches (uncorrected), occurred at 4 a. m., on the 17th. The wind at this time was W., force 7.

The same vessel again encountered heavy squalls on the 25th, while running up the coast between Port Said and Gibraltar. Captain Higgins states that the lowest pressure was 29.81 inches (uncorrected), occurring at 4 p. m., in 36° 30′ N., 2° 18′ E. At this time the wind was SW., force 9.

On March 8 there was an area of low pressure south of Australia that drifted slowly northeastward and from the date of its first appearance until the 11th fresh to strong gales prevailed between Australia and the coast of New Zealand.

During the period of maximum intensity of this storm, three vessels encountered fresh to strong gales. These were the American S. S. *Las Vegas*, and the British steamships *Waiotapu* and *Maunganui*.

The *Las Vegas*, Capt. Joseph Fritsch, proceeding from Dunedin, New Zealand, to Melbourne, on March 8 encountered a westerly gale accompanied by heavy rain squalls and rough seas. Mr. A. C. Larsen, second officer, reports that the lowest pressure observed was 29.27 inches, this occurring at 6 a. m., in 42° 50′ S., 152° 50′ E. The wind increased by the 9th to force 9, NNW., continuing so throughout the day.

On the 9th the *Waiotapu*, Capt. J. F. S. Brown, proceeding from Auckland, New Zealand, to Melbourne, encountered this same gale while in 36° 13′ S., 163° 5′ E., reporting conditions similar to those experienced by the *Las Vegas*. Mr. B. S. Cave, observer, states that the lowest barometer, 29.30 inches, was recorded at 3:30 p. m., on the 9th. The wind at this time was W. by S., force 8, thence shifted to south by midnight and increased to a whole gale which continued throughout the morning of the 10th.

On the 11th this cyclone had passed over New Zealand and the center was reported to be off Auckland. The *Maunganui*, Capt. L. Worsall, westward bound from Raratonga, came within its influence 85 miles off East Cape, New Zealand, experiencing southwesterly gales, force 10, accompanied by high seas and severe rain squalls. Mr. W. Johnson, second officer, reported that the lowest observed pressure, 29.25 inches, occurred in 37° 37′ S., 179° 5′ W., about six hours before the gale was experienced. This gale lasted for two days and during that time the wind was steady and blowing from the southwest.

DETAILS OF THE WEATHER IN THE UNITED STATES

GENERAL CONDITIONS

The single outstanding feature of the month was the prevailing low pressure over the Atlantic as touched upon by Supervising Forecaster Bowie and others in the pages which follow.

Coupled with this deficit in pressure over the North Atlantic, there appears to have been a small excess in pressure over the North Pacific between Hawaii and the North American Continent. The consequence of this change in pressure distribution is reflected in the abnormalities of temperature and precipitation as shown in Chart III and on the inset map of Chart IV. The usual details follow.

CYCLONES AND ANTICYCLONES

By W. P. DAY

The general path of the cyclones moving across the United States during the month of March was considerably depressed toward the south, and there were several developments into important storms, especially along the Atlantic coast. At the same time, air pressure was almost continuously high over the interior of Canada, apparently with a peak of high pressure near or over the Hudson Bay region. In fact the southern edge of this area coming within the limits of observation persisted without break from the 6th to the 24th, during which time no low-pressure area was charted within the region. It is also interesting to note in this connection that the pressure was continuously below normal over the Azores from the 1st to the 27th with an average depression of about half an inch. Bermuda also showed a large deficiency of pressure from the 6th to the 27th.

FREE-AIR SUMMARY

By V. E. JAKL, Meteorologist

The wind resultants for the month show for the four northern aerological stations a decidedly more northerly component than normal at all levels. The influence of this northerly tendency of the winds is also noticeable in the observations at the southern stations, where the wind resultants show a less southerly tendency than normal at most levels.

The thermal significance of the wind resultants is immediately apparent in the monthly mean temperatures. (See Table 1.) It was colder than normal to the upper limit of observations at all stations, the departures being especially pronounced in the higher levels at the northern stations and at Due West. At Groesbeck, where the departure from the normal wind direction was least, the temperature departure was also least. The departure of temperature with altitude showed the greatest range over Ellendale, where the temperature averaged nearly normal at the surface, but became progressively more below normal with increasing altitude. In this connection attention is called to Chart III, this REVIEW, which shows a positive departure at the surface along the northern boundary of the country. It is evident from the aerological data that this positive departure, at least east of the Rocky Mountains, prevailed at the surface only. The abnormally-low temperatures were associated on the whole with relative humidities higher than normal, except that about normal humidities obtained at Groesbeck, and in the lower levels at Due West.

The observed variance of wind from the normal and consequent depression of temperature occurred at more or less scattered intervals during the month, although a rather general and pronounced period of cold weather prevailed toward the close of the first decade. The dominant weather-map conditions, to which these departures from the normal can be attributed, appear to have been mainly a persistence of high pressure over middle sections of the country and low pressure over the North Atlantic; also a movement of LOWS across the country somewhat south of their usual path. (See Storms and Weather Warnings, Washington forecast district, p. 178, this REVIEW.) The resultant lowering of temperature, however, does not appear to have been due entirely to the northerly winds implied from this pressure distribution during the month, as numerous instances were recorded of temperatures below normal in winds having a strong southerly component. The most conspicuous examples were found on the 16th and 22d, on which dates, in the line of stations from Ellendale on the north to Groesbeck on the south, temperatures well below the average for the season were observed at practically all levels in winds draining northward from the rear of a ridge of high pressure extending southeastward across the country. An example is also found at Broken Arrow on the 22d, and on other dates (see p. 174) of an apparent exception to the known relation of temperature to wind direction, viz, a fairly well-defined fall in temperature in a southeast wind aloft. The explanation seems to be a reinforcement of the HIGH to the northeast, and the development of a LOW to the south.

A record of extremely low temperatures aloft for a southern station was obtained at Due West in the series of observations on March 10–11. The observations were made in the rear of the LOW that appeared over New Mexico on the 8th, a discussion of this LOW in its earlier stages appearing on page 161 of this REVIEW. The lowest temperature recorded, −20.8° C. at 2,500 meters altitude late at night of the 10th, was 22° lower than normal for that level, and practically the same as the lowest temperature recorded at the same level at the most northerly stations (Ellendale and Drexel), 36 hours previously. It is obvious from this observation that under certain conditions of pressure distribution and temperature conditions in its path, a cold mass of air can be transported great distances south or southeast without material gain in temperature. The temperature and wind direction record of this series of observations appears in the following table:

Wind directions and temperatures over Due West, S. C., on March 10–11, 1924 (see also Table 1, p. 174)

[Altitude, M. S. L., meters]

Date	Time	Surface	500	1,000	1,500	2,000	2,500
10	2 p. m.	W. 4.5	W. 1.6	W. −3.1	WNW. −7.1	W. −10.7	
10	7 p. m.	WNW. 1.0	WNW. −2.1	W. −7.1	W. −11.6	WNW. −15.0	WNW. −18.1
10	11 p. m.	WNW. −2.6	WNW. −5.0	WNW. −9.0	WNW. −12.8	WNW. −16.6	WNW. −20.8
11	3 a. m.	W. −3.9	W. −6.2	WNW. −9.9	WNW. −12.6	WNW. −13.7	NW. −14.0
11	8 a. m.	W. −3.5	WNW. −5.3	WNW. −8.1	NW. −9.8	NW. −6.0	NW. −8.5
11	Noon	WNW. 3.0	W. −0.5	WNW. −3.6	NW. −4.6	NNW. −5.2	NNW. −6.3

Pilot-balloon observations showed as a rule a northerly component of free-air movement for the month over all stations, except that a marked southerly component was evident in some of the lower levels over the southern stations, particularly Groesbeck and Key West. The highest velocity recorded at any level was 54 meters per second from the WNW., shown at 7,200 meters altitude in a single theodolite observation made at Groesbeck on the 11th. Of more interest are the generally strong westerly winds observed in the first few kilometers above the ground on the 27th over an extended region comprising the stations of Broken Arrow, Denver, Drexel, Due West, Ellendale, Memphis, and Royal Center. Significance attaches to these winds, inasmuch as the weather map showed weak sea-level pressure gradients over the region concerned, and a pronounced LOW appeared central over Colorado on the following day. While a possible connection between these observed strong winds on the 27th and the development of the LOW on the 28th can only be assumed, the winds themselves can be explained from the depth of the latitudinal temperature gradient. Kite observations to 4,000 meters altitude are available on this date from Groesbeck and Ellendale, and show that the normal temperature gradient between the two stations was slightly exceeded at the surface and nearly doubled at 4,000 meters. The figures are shown in the following table:

Free-air temperatures over Ellendale, N. Dak., and Groesbeck, Tex., on March 27, 1924, and corresponding normals

[Altitude, M. S. L., meters]

Station	Date	Surface	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000
Ellendale	Mar. 27	−1.7	−1.9	−4.1	−5.0	−8.0	−11.2	−14.7	−18.3	−21.9
	normal.	−3.1	−3.2	−3.9	−4.9	−6.5	−8.8	−11.4	−14.0	−16.7
Groesbeck	do	17.8	16.4	19.4	19.0	15.7	11.5	7.8	4.3	0.7
		13.2	11.3	9.6	8.2	6.8	4.7	2.3	−0.3	−3.2

Winds having an easterly component extending to high altitudes were observed at the most northerly stations only, and considering the limited opportunities for observation to high altitudes imposed by weather conditions, were probably more frequent than the record shows. The places of occurrence and dates were as follows: Ellendale, Madison, and Lansing, 15th; Burlington, 22d; Ithaca, 23d; and Ellendale, 30th and 31st. As usual with easterly winds at high altitudes, the velocities were light. These easterly winds were observed in connection with high surface pressure, and undoubtedly were associated with the persistence of high pressure previously noted as prevailing over a considerable portion of the month.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during March, 1924*

TEMPERATURE (° C.)

Altitude. m. s. l. (m.)	Broken Arrow, Okla. (233 m.) Mean	Departure from 6-yr. mean	Drexel, Nebr. (396 m.) Mean	Departure from 9-yr. mean	Due West, S. C. (217 m.) Mean	Departure from 4-yr. mean	Ellendale, N. Dak. (444 m.) Mean	Departure from 7-yr. mean	Groesbeck, Tex. (141 m.) Mean	Departure from 6-yr. mean	Royal Center, Ind. (225 m.) Mean	Departure from 6-yr. mean
Surface	5.1	−4.7	−0.2	−3.4	9.8	−3.7	−3.7	−0.6	10.6	−2.6	1.7	−2.8
250	5.0	−4.7			9.5	−3.7			10.2	−2.4	1.4	−2.9
500	3.3	−4.6	−0.8	−3.4	8.0	−3.2	−4.0	−0.8	9.2	−2.1	−1.0	−3.3
750	2.0	−4.6	−2.4	−4.0	6.5	−3.2	−5.4	−1.7	8.5	−1.8	−2.7	−3.9
1,000	1.2	−4.6	−3.8	−4.9	4.7	−3.7	−6.9	−3.0	8.3	−1.3	−3.9	−4.3
1,250	0.8	−4.5	−5.1	−6.1	3.1	−4.0	−8.2	−3.8	7.8	−1.1	−5.0	−4.7
1,500	0.6	−4.1	−5.8	−6.5	1.9	−4.0	−9.2	−4.3	6.8	−1.4	−5.8	−4.8
2,000	−0.7	−3.8	−7.5	−6.4	0.3	−3.4	−11.6	−5.1	4.9	−1.9	−7.6	−5.0
2,500	−2.6	−3.4	−9.7	−6.2	−2.2	−3.8	−13.9	−5.1	2.7	−2.0	−10.5	−5.7
3,000	−5.2	−3.5	−11.8	−5.7	−4.7	−4.3	−16.9	−5.5	0.0	−2.3	−13.0	−5.9
3,500	−7.9	−3.7	−13.7	−4.9	−7.7	−4.9	−20.1	−6.1	−1.8	−1.5	−15.5	−6.2
4,000	−10.8	−3.7			−11.1	−5.5	−23.2	−6.5	−4.7	−1.5		
4,500	−13.6	−3.4			−14.8	−5.9	−25.8	−5.9				
5,000					−18.5	−5.9	−29.0	−5.8				

RELATIVE HUMIDITY (PER CENT)

Altitude. m. s. l. (m.)	Broken Arrow Mean	Departure	Drexel Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure
Surface	71	+5	77	+8	61	−2	75	−1	73	+3	79	+7
250	71	+5			61	−2			71	+2	79	+7
500	71	+6	76	+8	60	−3	75	0	67	+1	79	+9
750	71	+7	75	+9	61	−2	74	+5	64	0	78	+11
1,000	70	+8	74	+12	63	−1	73	+8	58	−2	75	+11
1,250	68	+10	72	+16	64	0	71	+10	53	−3	74	+13
1,500	62	+9	68	+16	63	−1	70	+11	52	0	73	+14
2,000	54	+9	65	+15	56	−2	69	+12	51	+8	75	+18
2,500	48	+6	63	+13	56	+5	66	+9	47	+9	68	+12
3,000	48	+8	63	+12	57	+11	70	+13	47	+12	71	+14
3,500	50	+8	63	+13	64	+21	73	+16	39	+6	76	+19
4,000	52	+11	60	+11	71	+27	70	+13	45	+9		
4,500	58	+15	60	+7	69	+27	63	+6				
5,000			60	+11	68	+27	56	−2				

VAPOR PRESSURE (*mb.*)

Altitude. m. s. l. (m.)	Broken Arrow Mean	Departure	Drexel Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure
Surface	6.62	−1.92	4.70	−0.59	7.64	−2.75	3.45	−0.41	9.74	−1.72	5.69	−0.75
250	6.56	−1.90			7.47	−2.75			9.18	−1.75	5.57	−0.74
500	5.93	−1.59	4.47	−0.53	6.79	−2.35	3.37	−0.38	8.09	−1.62	4.57	−0.78
750	5.38	−1.37	3.92	−0.54	6.18	−2.17	2.95	−0.31	7.35	−1.50	3.94	−0.81
1,000	5.02	−1.17	3.50	−0.49	5.65	−2.12	2.57	−0.39	6.49	−1.44	3.48	−0.78
1,250	4.61	−1.01	3.11	−0.45	5.11	−2.09	2.21	−0.52	5.52	−1.47	3.17	−0.70
1,500	3.98	−0.98	2.76	−0.44	4.46	−1.99	1.97	−0.57	4.95	−1.17	2.99	−0.59
2,000	2.95	−0.86	2.31	−0.38	3.55	−1.44	1.58	−0.58	4.19	−0.21	2.77	−0.28
2,500	2.13	−0.96	1.96	−0.33	3.06	−0.66	1.31	−0.49	3.27	−0.05	2.17	−0.43
3,000	1.79	−0.79	1.77	−0.17	2.62	−0.07	1.14	−0.29	2.57	−0.06	2.16	−0.17
3,500	1.47	−0.84	1.62	+0.03	2.40	+0.44	0.95	−0.20	1.68	−0.49	2.19	+0.10
4,000	1.22	−0.80			2.20	+0.71	0.76	−0.15	1.21	−0.68		
4,500	1.12	−0.73			2.02	+1.06	0.58	−0.13				
5,000					1.90	+1.06	0.39	−0.14				

TABLE 2.—*Free-air resultant winds (m. p. s.) during March, 1924*

Altitude, m. s. l. (m.)	Broken Arrow, Okla. (233 meters) Mean Dir.	Vel.	6-year mean Dir.	Vel.	Drexel, Nebr. (396 meters) Mean Dir.	Vel.	9-year mean Dir.	Vel.	Due West, S. C. (217 meters) Mean Dir.	Vel.	4-year mean Dir.	Vel.
Surface	N. 2° W.	2.8	S. 5° W.	1.9	N. 25° W.	2.4	S. 63° W.	0.7	S. 89° W.	3.6	S. 64° W.	2.2
250	N. 2° W.	2.7	S. 5° W.	2.1					S. 88° W.	3.8	S. 63° W.	2.5
500	N. 9° E.	2.5	S. 8° W.	3.4	N. 27° W.	2.5	S. 61° W.	0.9	S. 85° W.	5.0	S. 64° W.	3.4
750	N. 5° W.	2.2	S. 13° W.	4.6	N. 25° W.	3.3	S. 81° W.	2.1	S. 82° W.	7.1	S. 67° W.	4.9
1,000	N. 26° W.	2.3	S. 26° W.	5.5	N. 35° W.	4.0	W.	3.1	S. 81° W.	8.8	S. 67° W.	6.2
1,250	N. 55° W.	3.3	S. 38° W.	6.2	N. 45° W.	5.2	N. 82° W.	4.0	S. 86° W.	10.4	S. 68° W.	7.8
1,500	N. 75° W.	4.6	S. 55° W.	6.1	N. 42° W.	5.9	N. 83° W.	5.0	S. 86° W.	11.7	S. 72° W.	9.7
2,000	N. 81° W.	6.7	S. 69° W.	7.0	N. 42° W.	8.2	N. 83° W.	6.7	N. 88° W.	12.2	S. 77° W.	11.9
2,500	N. 84° W.	9.7	S. 79° W.	7.8	N. 53° W.	8.6	N. 86° W.	8.6	N. 75° W.	13.6	S. 87° W.	13.0
3,000	N. 84° W.	10.8	S. 85° W.	9.2	N. 42° W.	13.6	N. 86° W.	11.2	N. 84° W.	15.1	S. 85° W.	13.8
3,500	N. 86° W.	9.8	S. 78° W.	10.1	N. 54° W.	16.7	N. 81° W.	14.8	S. 87° W.	16.6	S. 82° W.	14.0
4,000	S. 30° W.	10.4	S. 66° W.	9.5	N. 81° W.	12.8	N. 77° W.	17.6	S. 86° W.	19.4	S. 80° W.	15.3
4,500	S. 30° W.	11.0	S. 57° W.	9.7	N. 45° W.	16.8	N. 79° W.	17.3	S. 68° W.	18.0	S. 87° W.	16.7
5,000	S. 45° E.	15.8	S. 56° W.	6.8	N. 68° W.	20.0	N. 75° W.	17.1				

Altitude, m. s. l. (m.)	Ellendale, N. Dak. (444 meters) Mean Dir.	Vel.	7-year mean Dir.	Vel.	Groesbeck, Tex. (141 meters) Mean Dir.	Vel.	6-year mean Dir.	Vel.	Royal Center, Ind. (225 meters) Mean Dir.	Vel.	6-year mean Dir.	Vel.
Surface	N. 1° E.	3.5	N. 37° W.	2.1	N. 52° E.	0.5	S. 3° E.	1.2	N. 36° W.	1.9	S. 43° W.	1.6
250					S. 71° E.	0.4	S. 4° E.	1.9	N. 36° W.	1.9	S. 40° W.	1.8
500	N. 3° E.	3.6	N. 42° W.	1.9	S. 4° E.	0.9	S. 8° W.	3.5	N. 53° W.	2.3	S. 46° W.	4.3
750	N. 3° E.	4.4	N. 68° W.	2.3	S. 22° W.	1.7	S. 21° W.	4.4	N. 59° W.	2.6	S. 53° W.	5.6
1,000	N. 3° E.	4.6	N. 77° W.	2.7	S. 43° W.	3.1	S. 34° W.	5.2	N. 62° W.	2.9	S. 61° W.	6.5
1,250	N. 4° E.	5.2	N. 73° W.	3.7	S. 60° W.	3.8	S. 42° W.	5.5	N. 62° W.	4.0	S. 68° W.	7.6
1,500	N. 4° E.	5.3	N. 75° W.	4.9	S. 71° W.	5.1	S. 48° W.	5.7	N. 64° W.	4.9	S. 72° W.	8.4
2,000	N. 3° E.	5.5	N. 76° W.	6.8	S. 73° W.	7.1	S. 61° W.	6.9	N. 53° W.	5.3	S. 77° W.	9.8
2,500	N. 12° W.	5.1	N. 75° W.	9.5	S. 78° W.	10.4	S. 67° W.	9.0	N. 7° W.	3.0	S. 80° W.	10.9
3,000	N. 32° W.	7.0	N. 76° W.	11.0	S. 80° W.	11.5	S. 71° W.	9.5	N. 58° W.	2.5	S. 86° W.	13.2
3,500	N. 58° W.	10.1	N. 82° W.	13.2	S. 88° W.	14.6	S. 76° W.	12.6	N. 37° W.	15.4	S. 86° W.	15.7
4,000	N. 75° W.	14.6	N. 88° W.	14.9	S. 82° W.	15.9	S. 72° W.	14.2	N. 45° W.	22.2	W.	14.0
4,500	N. 71° W.	10.4	S. 88° W.	15.3								
5,000	W.	14.9	N. 88° W.	17.3								

THE WEATHER ELEMENTS

By P. C. DAY, Meteorologist in Charge of Division

PRESSURE AND WINDS

Low barometric pressure over the eastern and southern portions of the country and apparently embracing much of the North Atlantic was the marked feature of the weather during the month. This condition was induced mainly by the passage eastward of a number of cyclonic areas which originated over the Southwest and developed materially as they progressed eastward in latitudes lower than usual, reaching the coast as storms of importance.

A storm of this character was first charted on the morning of the 7th over the far Southwest and moved by slow stages eastward, without material precipitation, until the morning of the 9th, when it was apparently central south of the middle Gulf coast, and precipitation covered a wide area from the middle Plains southeastward to the east Gulf States, snows occurring over the northern portions of the precipitation area, and some heavy rains to the southward. By the following morning the cyclonic conditions had developed materially, with important centers of action in the Ohio Valley and off the South Atlantic coast. By the morning of the 11th the main center was over Delaware and eastern Maryland, where the pressure was only slightly above 29 inches. High winds prevailed along and near the coast, heavy rains were falling over portions of the Middle Atlantic States and some heavy snows for the season occurred in western Maryland and adjacent areas. This storm continued its northeasterly course with undiminished energy, and was south of the New England coast by the 12th and to southward of Newfoundland within the following 24 hours.

Another important cyclone moved into the west Gulf section on the morning of the 19th and by 8 a. m. of the 20th was central as a storm of considerable force over the middle Gulf States, attended by precipitation over a wide area from the middle and southern Plains eastward. During the night of the 19th–20th the pressure at points in the lower Mississippi Valley was the lowest of record for March.

The storm moved to the Chesapeake Bay region during the following 24 hours and thence eastward toward the Bermuda Islands.

The most important cyclone of the month was first observed as an area of falling pressure to westward of the Rocky Mountains on the morning of the 27th, and during the following 24 hours moved to the vicinity of Colorado where the barometer had fallen sharply. As this cyclone moved eastward it developed greatly in energy, and at 8 a. m. of the 29th was central over Iowa as a storm of great severity with unusually deep depression of the barometer, the readings at the center falling below 29 inches, which at some points was the lowest observed in any month and at others the lowest ever observed in March. Heavy snows fell over portions of the northern and northwestern limits of the storm area as it moved eastward, and high winds caused much drifting; the snow was particularly heavy over a considerable area from South Dakota to Wisconsin, the depths ranging up to 2 feet or more at points in central Minnesota. Farther south frozen rain and wet snow caused damage to overhead wire systems, the loss being confined largely to sections of northern Iowa and southern Wisconsin. During the 30th and 31st the storm moved to the lower St. Lawrence Valley, but it diminished greatly after passing the Great Lakes region. Precipitation from this storm was widespread, covering nearly all districts from the Great Plains eastward, and it was heavy in many sections of the Ohio and middle Mississippi Valleys.

The month was remarkably free from anticyclones, in fact no important high pressure area traversed any extensive region, although southern extensions from a rather permanent anticyclone that appeared to persist during the greater part of the month over central Canada, were projected into the districts between the Rocky Mountains and Great Lakes on a number of dates.

The pressure distribution as a whole was materially different from that usually present in March. Over the districts from the Mississippi River eastward the average pressure was below normal, becoming markedly so over the more eastern districts where the depression was a quarter of an inch or more, and more or less persistent during the entire month. The average pressure was likewise lower than normal over the Plateau and southern Rocky Mountains and throughout the entire south.

A small area along the coast from northern California to Washington had pressure for the month slightly higher than normal and from Nebraska and Wyoming northward into Canada the average pressure was likewise greater than normal.

Compared with the preceding month the pressure was lower in all parts of the country, and while this is the normal condition, the decreases were usually much greater than normal, this being particularly true over the Plateau region, the New England States and the Canadian Maritime Provinces.

The sharp falling off in the average pressure from the interior of Canada to the southeastward, southward, and southwestward, materially favored air drainage in southerly directions, and the prevailing winds for the month were mainly from northerly points over all parts of the country from the Rocky Mountains eastward.

The main high winds of the month were associated with the cyclone that moved northward along the Atlantic coast on the 11th and 12th, and with that moving from the Middle Plains northeastward to the Great Lakes on the 28th to 30th. During the passage of this latter storm unusually high winds were observed generally at points within its influence, some stations reporting the highest velocities ever observed, and in other cases local tornadoes occurred, particularly in Oklahoma, where at and in the vicinity of Shawnee eight or more persons were killed and much property damaged. Local tornadoes, but without severe damage, were reported from points in Illinois and Missouri.

A list of the important storms of the month appears at the end of this section.

TEMPERATURE

Temperature conditions during March, 1924, on the whole were more typical of winter than of spring, particularly over the southern and western districts where coolness was almost continuous and the average temperatures for the entire month were in many cases lower than those of February preceding. On the other hand, over the northern sections from the upper Missouri Valley to the Great Lakes and Northeastern States, and generally over the Canadian Provinces east of the Rocky Mountains, the temperature characteristics were more springlike.

As in the preceding month there was a noticeable absence of important 24-hour changes in temperature; in fact, over the northern sections and in Canada practically no change as great as 20° in 24 hours occurred during the entire month, where usually such variations are frequent. In the central and southern districts there were several such, though confined mainly to small areas.

Considering the temperature by weekly periods the week ending March 4 had averages on the whole above the normal in all districts, save from the lower Rio Grande Valley eastward, the week being particularly warm over the central and northern districts between the Rocky Mountains and the Great Lakes and Ohio Valley.

The week covering the period March 4 to 11 was mainly cold, only small areas from the vicinity of the Great Lakes to the Northeastern States and over the Pacific coast sections having average temperatures above normal. No unusual cold occurred during the week, but temperatures were continuously low over the greater part of the country, and freezing extended southward to the Gulf coast and into northern Florida.

For the 7-day period ending the 18th, the weather continued cold over nearly all parts of the country, the average temperatures for the period ranging from 10° to 18° below the normal over a large area extending from the central Rocky Mountains southeastward to the East Gulf and South Atlantic States. Freezing temperatures again reached well toward the Gulf coast, and they were frequent in the interior districts. The following 7-day period continued cold throughout over much of the territory having such conditions during several preceding weeks, though a small area from the Dakotas eastward to New England had temperatures above normal.

The last week of the month continued cold generally over the central valleys and western districts, the temperatures during this period continuing particularly low over the Rocky Mountain and Plateau districts, as had been the case throughout practically all the preceding weeks.

The principal warm periods of the month were on the 1st from North Dakota to Idaho and generally over the Plateau region, and from the 27th to 31st over the greater part of the remainder of the country.

The highest recorded temperature, 104°, occurred in Texas, though in most of the Southern States 90° was not reached, and in some of the Northern States the maximum temperatures did not reach 60°.

The coldest periods of the month ranged between the 1st and 31st and no large area had its lowest temperatures on any single date. Temperatures below zero occurred over most northern districts and generally in the mountains of the West; the lowest observed, −26°, was reported from two points in Colorado.

Although much cold weather was the rule, yet no extremely low temperature records were broken.

The averages for the month were below normal over the greater part of the country, the month being particularly cold over the central and southern districts. Over a large area from the middle and southern Plateau region eastward to the Gulf States the month was either the coldest or among the coldest of record for March. Along the northern border, however, from eastern Montana to New England and southward to the Chesapeake Bay region, the month was warmer than normal, and similar conditions prevailed over Canada, the excesses being greatest over the more northern districts, where the month was far warmer than usual for March.

PRECIPITATION

Over the greater part of the country from the Mississippi Valley eastward precipitation was mainly less than is usually received in March, although there was a considerable area from Iowa and Minnesota southeastward to the Ohio Valley and Middle Atlantic States with amounts somewhat above normal, and portions of northern and central Florida had heavy falls. In the Great Plains and Rocky Mountains the precipitation was mainly above normal, and the southern Plateau and southern California likewise had precipitation above normal, while in the far Northwest there was a general deficiency.

In the Rocky Mountain regions much snowy weather prevailed, and in most other sections to the eastward the precipitation, though frequently deficient as compared with the average fall, was well distributed through the month, although in portions of New York there was little till near the end of the month, and portions of southern Florida had little or none, although the northern and central portions of that State had some heavy amounts.

In California the severe drought that had persisted for so many months was partially broken, particularly in the southern portions where the total fall was somewhat above normal.

In Oregon the precipitation was scanty for a spring month, and on the whole it was among the driest of record for March, and there was a large deficiency in the adjacent State of Washington.

The greatest monthly precipitation, 13.70 inches, was reported from northern Florida, and none was observed at a point in the southern part of the same State. At two points in Texas no precipitation was observed during the month, and none fell at a point in eastern Washington.

The precipitation attending the storm of the 28th-30th was the most widespread of the month and heavy falls were recorded over large areas. In western Maryland and adjacent portions of other States, the heavy rains, in connection with melting snow which had already swollen the streams in that vicinity, caused one of the worst floods known in portions of the upper Potomac River, a full account of which will be found in another section of this issue.

SNOWFALL

There was a wide distribution of snow during the month, and some unusual falls were reported.

About the 13th to 14th heavy snows occurred over portions of Alabama and adjacent States amounting to nearly a foot in some sections, and at Montgomery a depth of nearly an inch and one-half was the first measurable snowfall ever observed at that place in March.

In the Southern Plains region the month brought unusually heavy snowfall, notably in western Kansas and portions of adjacent States, where all records of snowfall in March were broken, the total fall ranging up to 3 or 4 feet and in one case a total of more than 5 feet was measured. Heavy snows also fell over a wide area during the severe storm of the 28th–30th, the greatest depths ranging up to two feet or more, occurring from the middle plains region northeastward over Iowa, northern Missouri, and central and southern Minnesota to the upper Lakes.

High winds attending the snowfall caused much drifting and interference with traffic and to the southward of the heavy snow area more or less ice formed on overhead wire systems and much loss to these and delay in communication resulted, particularly in southern Wisconsin and portions of Iowa.

In the western districts there was much snowfall in the Rocky Mountain region and the outlook for a good supply of water for the coming summer was greatly improved; also in most of the Plateau region there was much improvement in the outlook, although over the northern portions the stored snow is still less than normal.

In the mountains of California there was considerable snow during the month, but the seasonal fall is still far below the normal and the indications are that the water shortage for irrigation and power purposes will be serious.

In connection with the general rain and snowstorm of the 27th to 30th there were many reports of the deposit of a brownish substance in connection with both the rain and snow, over wide areas, but particularly in the upper Mississippi Valley and adjacent districts. In this connection it is interesting to note that on the 27th and 28th there were high winds in many portions of New Mexico, much plowed land was badly drifted, and in some sections of the State the dust storms were reported as the worst ever known.

RELATIVE HUMIDITY

The moisture conditions existing in the atmosphere during March, as indicated by the average relative humidity, were mainly not far from the average, except for a rather marked excess over the Great Plains, where much cold, inclement weather prevailed, and a general deficiency in the far western sections, where the weather was warmer and there was mainly a considerable deficiency in the precipitation.

SEVERE LOCAL STORMS, MARCH, 1924

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path (yards)	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Apalachicola, Fla	9	4:35-7:05 a. m.			$1,000	Wind	Fishing boats damaged	Official, U. S. Weather Bureau.
Maryland, southern Pennsylvania, and northern Virginia.	10-11			2	1,000,000	High winds and heavy fall of moist snow.	Telephone, telegraph, and lighting systems crippled; about 2,500 poles blown down; electric schedules interrupted; trees injured.	Official, U. S. Weather Bureau; Sun (Baltimore, Md.)
New York, N. Y., and adjacent seacoast.	10-11					Gale and rain	Shipping paralyzed; wire communication interfered with and some property damage.	Morning Sun (Binghamton, N. Y.).
Richmond, Va	10-11					Wind and snow	Communication lines badly crippled; traffic delayed.	Official, U. S. Weather Bureau; News Leader (Richmond, Va.).
Atlantic City, N. J	10-11					Wind, rain, and snow.	No damage reported	Official, U. S. Weather Bureau.
Providence, R. I	11-12				800,000	Wind and snow	Telephone and light companies suffer heavy loss; car service tied up; other property damage.	Do.
Harper, Montgomery, and Elk Counties, Kans	28				5,000-10,000	Series of 5 tornadoes.	Farm buildings, fences, wires, and some stock cars damaged.	Do.
Ludington, Mich	28-29					Wind, rain, sleet, and snow.	Damage principally to overhead wires	Do.
Oklahoma	28-29			8	841,000	Tornadoes and high winds.	Tornadoes at Noble and Shawnee, resulting in 68 injured. Severe winds in other parts of State, especially Oklahoma City and southern part of Tillman County.	Do.
Illinois	28-29					Winds	Residences and other buildings damaged; trees, fences and poles destroyed; orchards injured. At Alton tornadic wind injured 1 person.	Do.
Missouri	28-29			3	204,000	Tornadoes and winds.	Orchard trees uprooted; wires broken; stock killed, and some buildings blown down. One tornado at Oregon, another traversed New Madrid, Scott, Bollinger, and Girardeau Counties causing much property damage.	Do.
McCracken and Ballard Counties, also cities of Newport and Covington, Ky.	28-29					High winds	Towns of Lamont, Grahamville, and Maxon suffered severely in loss of buildings; extreme damage in vicinity of Newport and Covington.	Do.
Southwest Arkansas and Northwest Louisiana.	28-29				250,000	do	Heavy damage in gas and oil fields	Do.
West Texas	28-29					Wind and sand	Crops, buildings, and communication lines considerably damaged; 3 persons injured near Vernon.	Do.
Southeast portion of Wisconsin.	28-30				1,000,000	Sleet, snow, and wind.	Serious damage to trees and overhead wire systems; highways blocked and railway and interurban traffic delayed.	Do.
Evansville, Ind	29					High winds	Considerable damage throughout the city	Do.
Sullivan County, Ind	29	a. m.			200,000	Winds	General damage done; 5 persons injured	Star (Terre Haute, Ind.).
Terre Haute, Ind	29	9:45 a. m.			5,000-6,000	do	Interurban car service delayed; wires and poles damaged.	Official, U. S. Weather Bureau.
Cincinnati, Ohio	29	a. m.				do	Considerable damage in various parts of the city	Do.

STORMS AND WEATHER WARNINGS

By EDWARD H. BOWIE, Supervising Forecaster

From its beginning to its end the month of March gave winter cyclone types, at times of pronounced intensity, over practically all parts of the country. It is noteworthy that during much of the month there was a suppression of the rather common type of cyclone that moves along the northern border after having passed into British Columbia from the North Pacific Ocean or Alaska. Hence, cyclones which crossed the country did so in low latitudes, and, as is the case in practically all instances, these disturbances were attended by widespread precipitation, much of it in the form of snow along and to the north of the track of the center of the cyclones and were also attended by high winds and by the carrying far southward of cold air by the local wind circulations as the cyclones passed eastward.

One naturally asks why March of 1924 should conform so closely to typical February cyclonic types rather than to types characteristic of early spring? Why did the cyclones move in low rather than high altitudes, and the month turn out to be one of much cloudiness, unusual storminess, and cold weather? Unquestionably the immediate cause is seen in the phenomenally low barometric pressure which persisted throughout the month over much of the North Atlantic Ocean, which permitted nearly all cyclones to reach the Atlantic coast south of Cape Cod, whereas under normal pressure conditions they pass off the continent by way of the St. Lawrence Valley. During March, 1924, the upper air winds over the United States east of the Rocky Mountains were commonly observed from the West and Northwest, whereas, ordinarily they are from the West or Southwest a considerable part of the time. Moreover,

relatively high barometric pressure over eastern and southeastern Alaska, as was observed during much of the month of March, 1924, is commonly associated with low barometric pressure over that part of the United States west of the Rocky Mountains, in which region of low barometric pressure, many of the cyclones of the month were first observed.

WASHINGTON FORECAST DISTRICT

Storm warnings were required at frequent intervals for the Atlantic and Gulf coasts. The first display was on the 8th, when at 9 a. m. northwest storm warnings were ordered for the Atlantic coast from Delaware Breakwater to Portland, Me., when a disturbance of increasing intensity was central in the vicinity of Nova Scotia. This was followed by a display of storm warnings on the east Gulf Coast on the morning of the 9th; and on the 10th the display of storm warnings was extended to the entire Atlantic coast north of Juniper Inlet, Fla. This disturbance developed into what may be regarded as the severest and most prolonged disturbance of the month. On the morning of the 10th when the primary storm center was over the Ohio Valley there were evidences of the formation of another disturbance off the Carolina coast. As ordinarily happens when this type of pressure distribution occurs the primary cyclone disappears while the secondary increases greatly in intensity. This happened in this case, so that within 24 hours the primary cyclone disappeared while the one off the Carolina coast developed, moved northward and gained great intensity. By the morning of the 11th the pressure had fallen to 28.82 inches at Cape Henry, Va., and gales were general along practically the entire Atlantic seaboard. On the evening of the 10th when it was apparent that this condition would take place, the ordinary storm warnings were displaced by "whole gale" warnings on the Atlantic coast between Delaware Breakwater and Portland, Me. It was necessary to continue warnings on the Atlantic coast as far south as Savannah, Ga., into the 13th.

This great storm had scarcely passed off the coast, when it became necessary on the 13th to display storm warnings on the east Gulf and South Atlantic coasts, in connection with a disturbance that passed rapidly eastward from near the mouth of the Rio Grande to the South Atlantic coast, attended by strong winds and general rains and snows in the Southern States. During the 16th and 17th small-craft warnings remained displayed at and north of the Virginia Capes, while during the period, the 19th to 21st, storm warnings were displayed on one or more of these days for the entire Atlantic and east Gulf coasts. The disturbance in question was central the morning of the 19th near the mouth of the Rio Grande. It gained intensity very rapidly and started to move east-northeastward. On the morning of the 20th the primary center was over western Tennessee, while at the same time there were unmistakable indications of the formation of a secondary cyclone center over southern Georgia. The primary center over western Tennessee advanced northeastward and disappeared over the upper Ohio Valley, while the secondary over southern Georgia gained markedly in intensity and moved north and became a storm of marked severity by the time its center passed east-northeastward off the Virginia Capes on the 20th. Another disturbance central the morning of the 26th over the upper Ohio Valley made necessary the display of storm warnings at that time on the Atlantic coast at and north of the Virginia Capes, and on the 28th when a disturbance of pronounced character was central over Kansas, storm warnings were displayed on the east Gulf coast and on the 29th when the center of this disturbance was over southern Iowa, storm warnings were displayed on the Atlantic coast at and north of Jacksonville, Fla.

Frost warnings were required during the month on a number of days for the Southern States, and on the 29th cold wave warnings were ordered for the Ohio Valley and Tennessee.

CHICAGO FORECAST DISTRICT

For a winter month, March, 1924, in the Chicago Forecast District was comparatively quiet, from the point of view of the forecaster. Only one severe storm affected the district, but that indeed was a notable one; further reference to it will appear later in this report. Sudden and marked temperature fluctuations were largely absent during the month, and as a corollary but few cold waves occurred. The only cold wave warnings issued were those on the 6th for northeastern Minnesota, and on the 29th for northwestern Missouri and southeastern Iowa. The former was not verified, although the antecedent conditions appeared to have been almost ideal. Probably the explanation lies in the fact that the cyclonic area centered over western Lake Superior on the morning of the 6th was sluggish in its further movement. Twenty-four hours later the center had advanced only to northern lower Michigan. The cold wave warnings of the 29th were verified, but as developments showed, the warnings should have embraced in their scope northern Illinois and southern lower Michigan, even though a technical verification was not attained over all these two areas.

Warnings, advisory as to expected storm conditions on Lake Michigan, were issued on the 3d, 20th, 28th, and 29th, the last mentioned being a continuation of the warning of the previous date. On the night of the 3d a disturbance of increasing energy and with a central pressure of 29.36 inches was over northeastern Kansas, advancing toward the Great Lakes. Accordingly, advices were issued to the effect that strong shifting winds and moderate gales might be expected over Lake Michigan. Although the disturbance maintained its low pressure as it crossed the Lakes, no winds of storm force were registered. The next advisory warning was issued on the 20th, when a disturbance of rather marked character was central in western Tennessee with a north-northeastward movement. On the afternoon of the date in question a maximum velocity of 36 miles an hour occurred at Chicago, and 31 miles at Milwaukee.

The most important storm of the month, and in fact one of the most severe storms of record in certain portions of the district, prevailed on the 28th, 29th, and 30th. It appears to have originated, or at any rate it developed, over the northern Rocky Mountain region. By the morning of the 28th the center was in eastern Colorado with barometer readings of 29.24 inches at Denver and Pueblo. Thence a north-northeast course was taken, which carried the center across the extreme southern end of the upper Lake region and later down the St. Lawrence Valley. By the night of the 28th the storm was showing marked intensity, and accordingly a warning, in which vessel masters were advised to exercise caution, was issued for Lake Michigan. During the passage of the disturbance from Kansas to the upper Lake region sharply contrasted weather conditions prevailed on the two sides (northern and southern) of the storm. Over the former area a great snowstorm occurred, accompanied

by northeast gales. In the Twin Cities (St. Paul and Minneapolis) the storm was especially intense. On the southern side of the disturbance severe thunderstorms were a feature, accompanied by southwest to northwest gales. In portions of Kansas and Missouri some tornadoes occurred. An interesting feature of the storm was a deposit of "red mud" over a wide area, including at least eastern Iowa, southern Wisconsin, and northern Illinois.

Other special warnings issued during the month were those for stock interests in South Dakota, Nebraska, Kansas, and Wyoming on the 15th, and the western portions of Kansas and Nebraska on the 28th; also a heavy-snow warning for northern Missouri on the 16th.

Frost and cold-wave warnings for the benefit of the strawberry interests in southwestern Missouri were begun on the 15th, this being an annual feature of the work of this office. The season lasts until April 20.—*C. A. Donnel.*

NEW ORLEANS FORECAST DISTRICT

A cold wave of considerable severity overspread the greater portion of the district, extending to the coast, on the 9th and 10th, for which timely warnings were issued. Warnings which were verified were issued on the 13th for a cold wave on the Texas coast. Warnings were issued on the 16th, 17th, and 30th for cold waves which occurred over limited areas in the northwest portion of the district. Conditions were threatening on the 31st, and cold-wave warnings were ordered for the Texas coast; a decided fall in temperature occurred, but the lowest temperature was 42° to 46°. No cold waves occurred without warnings and no warnings were issued which were not justified.

Storm warnings were displayed on the Texas coast on the 9th, 13th, 17th, 22d and 28th, and on the Louisiana coast on the 13th and 19th. Storm winds occurred with each display on the Texas coast, but at New Orleans the velocities did not quite reach the requirement for verification. Small-craft warnings were issued for portions of the West Gulf coast on the 3d, 8th, 9th, 12th, 13th, 15th, 16th, 19th, 22d, 28th, and 31st, all of which were justified. No storms occurred without warnings and no warnings, except as needed, were issued.

Special wind warnings were issued on the morning of the 28th and distributed over the States in the district as follows: Louisiana, increasing southerly winds; Arkansas, thunderstorms, fresh to strong southerly winds, probably gales, this afternoon and tonight; Oklahoma, strong southerly winds this afternoon, shifting to northwest early Saturday; east Texas, fresh to strong southerly winds this afternoon and to-night, shifting to westerly Saturday. Damaging winds occurred in Arkansas, Oklahoma and northern Texas.—*I. M. Cline.*

DENVER FORECAST DISTRICT

The month was especially cold and stormy throughout, with a succession of LOWS advancing across the district from the Pacific coast or from the middle and southern portions of the Rocky Mountain Plateau.

On the morning of the 2d, when a disturbance of marked intensity was central over Nevada, livestock warnings were issued for western Colorado, northern New Mexico, northern Arizona, and Utah, snow and much colder weather, with strong shifting winds, having been forecast for that territory. Light snow, with considerably lower temperatures and fresh to strong shifting winds, attended or followed the passage of the storm eastward.

Livestock warnings were also issued on the morning of the 8th for southwestern Colorado and northern New Mexico, when another disturbance was central over that region. Light to moderately heavy snow, attended by strong shifting winds, occurred during the 8th in the territory designated, followed by a sharp fall in temperature that amounted to a cold wave at Santa Fe and Durango on the morning of the 9th.

On the morning of the 15th, when a disturbance of unusual intensity was central over western Colorado, with a pressure of 29.34 inches at Grand Junction and rapidly increasing pressures to the northward and northwestward, warnings of a moderate cold wave were issued for western Colorado, northeastern Arizona and southern Utah "to-night" and for northern New Mexico "to-night and Sunday." The warning was extended to southern New Mexico on the evening of the same date. The temperatures in northeastern Arizona and southwestern Utah were 20° lower on the evening of the 15th than at the same time on the 14th, with a minimum of 14° at Modena and of 18° at Flagstaff on the morning of the 16th. A sharp fall also occurred in the remainder of the territory for which the warnings were issued, but it was not sufficient to amount to a cold wave, another LOW that produced a modifying effect having begun to develop over Nevada during the 16th.

Warnings of a moderate cold wave in southeastern Colorado were issued on the morning of the 28th, when the pressure at Denver and Pueblo had fallen to 29.24 inches. From the temperatures reported from extreme western Kansas, the warning appears to have been verified over a portion of southeastern Colorado, although the fall at Pueblo amounted to but 14° during the following 24 hours, with a minimum of 36° reported from that station on the morning of the 29th.

A cold wave without warning occurred at Santa Fe and Durango on the morning of the 9th, although, as already stated, livestock warnings had been issued for southwestern Colorado and northwestern New Mexico. A local cold wave, without warning, also occurred at Pueblo on the morning of the 17th.

The following frost warnings were issued: 5th, 6th, 28th, and 29th, southern New Mexico; 8th, south central and southwestern New Mexico and southern and western Arizona; 9th, southwestern Arizona; 11th, south central and southwestern New Mexico; 12th, south central and southwestern New Mexico and southern Arizona; 15th, 16th and 22d, southern Arizona; 19th, south central and southwestern Arizona; 23d, southeastern New Mexico; 30th southern New Mexico and south central and southwestern Arizona.

Freezing temperature warnings were issued as follows: 5th, 8th and 17th, extreme southeastern New Mexico; 9th and 19th, southern New Mexico and southeastern Arizona; 13th, 16th and 22d, southern New Mexico; 30th, extreme southeastern New Mexico and extreme southeastern Arizona; 31st southern New Mexico.

As a rule, the conditions forecast were verified by temperatures favorable for the formation of frost, or by the occurrence of frost or freezing weather.—*J. M. Sherier.*

SAN FRANCISCO FORECAST DISTRICT

The pressure movements over this district during March, 1924, were of the type usually associated with early spring. The storms which entered the continent south of the international boundry, were of small area and rapid movement and developed greatly in energy after passing inland, while the large storms from the

north Pacific passed inland at a high latitude and exerted but little effect on the weather of the Pacific coast states.

During the last decade of the month a series of small storms, some moving southeastward from the Washington coast and others moving inland from off the northern California coast, passed eastward over the southern portion of the district and broke the long drought in California.

Storm warnings were ordered as follows: Northwest warnings at San Francisco on the 11th, and at Point Reyes on the 16th; and southwest warnings from Port San Luis to San Diego on the 20th.

Livestock warnings were issued in eastern Oregon and Idaho on the 14th; and in Nevada, Idaho, eastern Oregon and eastern Washington on the 18th, and 27th. The following commendation of these warnings is extracted from a letter received from the superintendent of the eastern Oregon branch of tne Oregon Agricultural College:

"Many thanks for your telegrams relative to changes in weather conditions. This information was immediately given to our stockmen, and I assure you it was appreciated very much."

Frost warnings were issued as follows: 13th, in Oregon, 15th, Oregon and Washington; 16th, northern California; 18th, and 23d, Oregon and Washington; 25th, Oregon and Washington; 27th, northern California; 29th, interior of California; 30th, northern California and Oregon.—*G. H. Willson.*

RIVERS AND FLOODS

By H. C. FRANKENFIELD, Meteorologist

Except for the floods of March 28–29 in the upper Potomac River, and on and after March 29 in the Monongahela and Ohio Rivers and their tributaries, no particularly destructive floods occurred in the principal rivers of the United States during March.

The Potomac River flood was caused by a combination of heavy rains with high temperatures that rapidly melted the heavy snow covering that had fallen over the drainage area during the month of March, from 3 to 4 feet remaining in the mountains at the time of the rains and high temperatures. In the North Branch of the Potomac River the flood was the greatest since the memorable flood of June 1, 1899, and in some localities was thought to have at least equaled the latter flood. Many towns were flooded, houses and bridges carried away, highways overflowed and destroyed, and great damage done in many other respects. In the town of Kitzmiller, Md., five lives were lost in the rush of the flood waters, but there were no other fatalities except one in the Shenendoah River near Harrisonburg, Va., and another at Washington, D. C.

The flood was particularly destructive in the vicinity of Cumberland, Md., but fortunately without loss of human life. The following report on the Cumberland flood was prepared by Dr. Harvey H. Weiss, river and cooperative observer and health officer of Cumberland:

During March, 1924, heavy snowfalls occurred throughout western Maryland. During most of the month all roads were blocked with drifts of snow, in some cases 15 to 20 feet high. The mountains were also covered with at least 3 to 4 feet of snow. On the morning of March 29, 1924, the maximum temperature having risen on the 28th to 65°, a heavy rainfall occurred, beginning at about 2 a. m. The rainfall between 2 a. m. and 8 a. m. was 1.63 inches. This rainfall, together with the snow washed down fron various mountains, brought down a tremendous amount of water which emptied into the Potomac River, and at 8 a. m., March 29 the water had risen to 8 feet at the Cumberland, (Md.) gage. The reading on the 28th of March was 4 feet 3 inches.

Wills Creek which flows into the Potomac River at Cumberland was out of its banks at 8:30 a. m. At this time the lowlands along the river at Cumberland and also the lowlands of Ridgeley, W. Va., which is opposite Cumberland, were beginning to flood. The Potomac River rose at the rate of 1 foot per hour until 3 p. m. and then the rise was about 1½ foot per hour until 6 p. m., when the river remained stationary for about one hour and then began to recede. The river gage being only able to measure 10 feet, the height from 11 a. m. on was estimated by the observer. According to measurement after the water receded it was found that the river at the gage had reached a height of 19 feet 2¼ inches. This reading may be high because of the fact that the water at the bridge may have been turbulent and therefore pushed higher than the actual level.

By 2 p. m. the entire lowland of Cumberland known as the "flats" was covered with 3 feet of water. Wills Creek flooded the main business section of Cumberland to a height of 3 feet. Mechanic Street, one of the main streets of the city, was like a river bed, the water rushing down the street at a great velocity. At 6 p. m. the crest of the flood was reached. By this time telephone, telegraph, and electric wires had been torn away, putting the city in complete darkness. Half of the west side of Cumberland was under 5 feet of water, and the center of the city contained about 4 feet of water. Most of the paving was washed away. The water had entirely receded at 5 a. m. on March 30 and cleaning up began immediately. There was no loss of life in Cumberland because of the flood. The property loss including railroad damage and bridges washed away was about $4,000,000 at a conservative estimate. From all information available the water on March 29, 1924, was 2½ feet higher than at any previous time in the history of Cumberland.

The South Branch of the Potomac River was not so high, yet the flood was one of considerable proportions, and with the flood from the North Branch, caused a severe flood below the junction of the North and South Branches, overflowing all lowlands, tearing out banks of the Chesapeake & Ohio Canal in many places, flooding railroad tracks, and doing much other damage of a miscellaneous character as far as the mouth of the Shenandoah River, except in the vicinity of Harpers Ferry, W. Va., where the damage done was negligible, although the river reached a stage of 20.7 feet on March 30, or 2.7 feet above the flood stage. The rise in the Shenandoah River did not reach flood proportions, and as a consequence the flood below Harpers Ferry was not dangerous, although there was considerable overflow at various places.

The damage done by the flood probably amounted to as much as $6,000,000 exclusive of railroad losses. Highway roads and bridges were reported to have been damaged to the extent of about $1,500,000.

Warnings were first issued for the flood on March 29, but the early interruption of telegraph service above Cumberland prevented the receipt of accurate information, and the warnings were therefore not as effective as they would otherwise have been.

The conditions antecedent to the floods in the Monongahela River of West Virginia and in the streams tributary to the Allegheny River in Pennsylvania were very similar to those that caused the Potomac floods, although they were not nearly so destructive. The crest stage at Pittsburgh, Pa., was 29.2 feet, or 7.2 feet above the flood stage, on March 30, and the damage done in the Pittsburgh river district amounted to about $1,000,000. However, the value of property saved through the accurate and timely flood warnings was reported to have been about $10,000,000.

The flood waters continued down the Ohio River, and at the close of the month the river had passed the flood stage of 40 feet at Point Pleasant, W. Va., at the mouth of the Great Kanawha River. The crest stage at

Parkersburg, W. Va., was 40.2 feet, or 4.2 feet above flood stage, at 10 a. m., April 1, and at Point Pleasant 44.5 feet, or 4.5 feet above flood stage, at 8 a. m., April 2. These crest stages were also very accurately forecast, and there were no losses or damage of consequence.

Report on the flood in the Ohio River and its tributaries below the mouth of the Great Kanawha River will appear in the MONTHLY WEATHER REVIEW for April, 1924.

The floods in the Muskingum, Hocking, and Scioto Rivers of Ohio also occurred on March 29, 30 and 31. They were well forecast and passed off with very little damage.

In the Miami River there was some overflow of lowlands unprotected by levees, but very little damage. According to reports the flood protection system took care of all surplus water exactly as had been calculated.

The Santee River of South Carolina was in moderate flood during virtually the entire month, and there was also a small flood in the Saluda River of the same State on March 21 and 22. Both floods were forecast at the proper times and the losses as reported amounted to only $3,465. The value of property saved through the warnings was reported at $17,900.

In the Tombigbee and Black Warrior Rivers of Alabama there were floods of considerable proportions on March 6 and 7 and a second crest of 52.8 feet, or 13.8 feet above flood stage, at Demopolis, Ala., on March 14 and 15. The river at Demopolis had been above flood stage since February 27, and the bottom lands from that place to the mouth of the river were inundated.

Statements as to losses from this flood were very indefinite, and totaled only $1,650. They were probably somewhat greater. The value of property saved through the warnings that were issued was reported as $24,250.

Floods in the Pearl and West Pearl Rivers of Mississippi and Louisiana were moderate and caused but little damage. The usual warnings were issued.

The flood of March 29–31 in the Maumee River of Ohio was caused by the heavy rains of that period. Warnings were issued promptly and no material damage resulted. The rise in the upper Grand River of Michigan was inconsequential.

The only important flood in the west Gulf district occurred in the Trinity River of Texas during the latter part of the month and the river was still in flood at the close of the month from Trinidad southward. There had also been a previous flood over the extreme lower portion of the river which continued from April 1 to 8, inclusive. At Dallas, Tex., the river reached a stage of 34.0 feet on March 25, or 9 feet above the flood stage. Warnings were issued frequently and as a result livestock and other movable property were salvaged, and as crops had not yet been planted, the losses were negligible. The reported value of property saved through the warnings was $30,000.

An ice gorge that formed during the night of March 7–8 in the Missouri River near Blencoe, Iowa, about 65 miles above Omaha, Nebr., continued for about 24 hours, and between 3,000 and 4,000 acres of valuable farm lands were inundated and several families were compelled to leave their homes.

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River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC DRAINAGE					
Potomac:	*Feet*			*Feet*	
Cumberland, Md	8	29	30	19.2	29
Harpers Ferry, W. Va	18	30	31	20.7	30
Washington, D. C	8	31	31	8.0	31
Cape Fear: Elizabethtown, N. C	22	(1)	2	23.4	1
Peedee: Mars Bluff, S. C	17	1	6	19.0	3
Santee:					
Rimini, S. C	12	(1)	10	15.2	3
		14	16	12.8	15
		21	31	14.4	26
Ferguson, S. C	12	(1)	(2)	13.7	4–5
Saluda: Chappells, S. C	14	(1)	(3)		
		21	22	14.8	21
EAST GULF DRAINAGE					
Coosa: Lock No. 4, Lincoln, Ala	17	8	8	17.1	8
Tombigbee:					
Aberdeen, Miss	33	6	7	33.8	6
Lock No. 4, Demopolis, Ala	39	(1)	22	52.8	14–15
Black Warrior: Lock No. 10, Tuscaloosa, Ala	46	(1)	(3)		
		6	7	53.6	7
Chickasawhay: Enterprise, Miss	21	(1)	(3)	22.2	Feb. 29
Pearl: Jackson, Miss	20	1	23	26.8	7–9
West Pearl: Pearl River, La	13	3	9	13.6	5–6
		12	29	14.1	23–24
GREAT LAKES DRAINAGE					
Maumee:					
Fort Wayne, Ind	15	29	(2)	19.2	31
Napoleon, Ohio	10	30	(2)	10.8	31
St. Joseph: Montpelier, Ohio	10	6	7	12.0	6
		29	(2)	12.1	30
Auglaize: Defiance, Ohio	10	30	(2)	12.0	31
Grand:					
Eaton Rapids, Mich	5	5	7	5.2	6–7
Grand Ledge, Mich	7	6	8	7.2	7
MISSISSIPPI DRAINAGE					
Stony Creek: Johnstown, Pa	10	29	30	16.0	29
Kiskiminetas: Saltsburg, Pa	8	30	30	11.8	30
Monongahela:					
Lock No. 15, Hoult, W. Va	22	29	29	26.6	29
Lock No. 10, Morgantown, W. Va	25	29	29	26.8	25
Lock No. 7, Martin, Pa	30	29	30	38.9	29
Lock No. 4, Pennsylvania	31	30	30	41.4	30
Cheat: Rowlesburg, W. Va	12	29	29	12.3	29
Youghiogheny:					
Confluence, Pa	10	29	30	19.0	29
West Newton, Pa	20	30	30	25.3	30
Ohio:					
Pittsburgh, Pa	22	30	31	29.2	30
Lock No. 2, Coraopolis, Pa	26	30	31	29.8	30
Dam No. 6, Beaver, Pa	30	30	(2)	39.8	30
Dam No. 12, near Wheeling, W. Va	36	31	(2)	38.4	31
Marietta, Ohio	33	30	(2)	38.9	31
Parkersburg, W. Va	36	31	(2)	39.4	31
Dam No. 19, near Tallman, W. Va	39	31	(2)		
Dam No. 22, W. Va	42	31	(2)		
Point Pleasant, W. Va	40	31	(2)		
Muskingum:					
Zanesville, Ohio	25	30	30	25.8	30
McConnellsville, Ohio	22	30	31	25.0	30
Marietta, Ohio	36	31	(2)		
Tuscarawas:					
Coshocton, Ohio	8	30	31	12.3	30
Gnadenhutten, Ohio	10	6	7	11.3	6
		30	(2)		
Walhonding:					
Walhonding, Ohio	8	29	30	12.6	29
Hocking:					
Athens, Ohio	17	30	31	17.8	30
Scioto:					
LaRue, Ohio	11	29	30	14.0	29
Prospect, Ohio	10	29	31	11.4	30
Bellpoint, Ohio	9	30	30	10.2	30
Circleville, Ohio	10	30	31	16.3	30
Chillicothe, Ohio	16	30	31	22.9	31
Oleontangy: Delaware, Ohio	9	29	29	10.0	29
Miami:					
Sidney, Ohio	12	29	29	12.6	29
Middletown, Ohio	15	31	(2)	15.4	31
Mad: Springfield, Ohio	10	29	29	11.5	29
Stillwater: Pleasant Hill, Ohio	13	29	29	15.0	29
Wabash:					
Bluffton, Ind	12	31	31	12.0	31
Lafayette, Ind	11	25	(2)		
Terre Haute, Ind	16	30	(2)		
White, East Fork: Seymour, Ind	10	31	(2)		

1 Continued from last month.
2 Continued at end of month.
3 Below flood stage at 8 a. m., Mar. 1.

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
White, West Fork:	*Feet*			*Feet*	
Anderson, Ind	12	30	30	15.2	30
Noblesville, Ind	14	30	31	16.4	30
Elliston, Ind	19	30	31	22.0	31
Edwardsport, Ind	14	30	([2])		
Tennessee: Riverton, Ala	33	7	10	34.1	8
Illinois:					
Morris, Ill	13	30	([2])		
Peru, Ill	14	([1])	([2])		
Henry, Ill	7	1	([2])		
Peoria, Ill	16	5	23	16.5	8–11
		27	([2])		
Havana, Ill	14	29	([2])		
Beardstown, Ill	12	([1])	([2])		
Sulphur:					
Ringo Crossing, Tex	20	18	23	23.0	21
Finley, Tex	24	23	26	24.9	25–26
North Platte: North Platte, Nebr	5	([1])	1	5.3	Feb. 28–29W
Grand: Chillicothe, Mo	18	30	([2])		
WEST GULF DRAINAGE					
Sabine:					
Logansport, La	25	([1])	1	25.2	1
Bon Wier, Tex	20	1	3	20.3	2
Trinity, Elm Fork: Carrollton, Tex	7	18	18	7.6	18
		20	22	7.9	20
Trinity:					
Dallas, Tex	25	16	25	34.0	21
Trinidad, Tex	28	20	([2])	37.2	26
Long Lake, Tex	40	31	([2])		
Liberty, Tex	25	([1])	8	26.6	2–4
		15	31	26.1	21–22
Guadalupe: Victoria, Tex	16	([1])	1	19.4	Feb. 29

[1] Continued from last month.
[2] Continued at end of month.

MEAN LAKE LEVELS DURING MARCH, 1924

By UNITED STATES LAKE SURVEY

[Detroit, Mich., Apr. 4, 1924]

The following data are reported in the "Notice to Mariners" of the above date:

Data	Lakes [1]			
	Superior	Michigan and Huron	Erie	Ontario
	Feet	*Feet*	*Feet*	*Feet*
Mean level during March, 1924:				
Above mean sea level at New York	601.07	578.69	571.26	244.88
Above or below—				
Mean stage of February, 1924	−0.26	−0.02	−0.01	+0.03
Mean stage of March, 1923	−0.40	−0.27	+0.26	+0.14
Average stage for March, last 10 years	−0.67	−1.28	−0.38	−0.60
Highest recorded March stage	−1.25	−4.26	−2.59	−2.93
Lowest recorded March stage	+0.41	−0.27	+0.43	+0.58
Average relation of the March level to—				
February level		+0.1	+0.2	+0.2
April level		−0.3	−0.6	−0.7

[1] Lake St. Clair's level: In March, 1924, 573.50 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS MARCH, 1924

By J. B. KINCER

Much of March was unseasonable cold in all except the extreme northern portions of the country, and rainfall was frequent in most of the principal agricultural districts, though the total falls were considerably less than normal from the Ohio and middle Mississippi Valleys southward. The cool weather was generally unfavorable for spring work, and the preparation of soil and the seeding of crops were considerably delayed. In the Southern States the first few days of the month and the last week were favorable for field work, but otherwise the continued wet soil and low temperatures were decidedly unfavorable.

The planting of cotton was very backward at the close of the month, though some planting had been done in the southern portions of the east Gulf States and in the Florida Peninsula. Planting in Texas was confined to the southern third of the State, and germination and progress of the early planted was generally poor because of the unfavorable weather. There was considerable corn planted the latter part of the month in the South, and at the same time much ground was prepared in central districts, but the preparation for planting was behind the average season.

The weather was generally favorable for wheat in the States between the Mississippi River and the Rocky Mountains, and the crop continued in good condition, especially in the Plains States, where soil moistures was unusually favorable. This crop showed some greening up in the Ohio Valley States at the close of the month, but on the whole the weather was rather unfavorable in that area. There was frequent alternate freezing and thawing, and heavy winterkilling resulted in many localities, especially in the central and southern portions of Indiana and Illinois and in Kentucky. It was fairly favorable for work in the spring wheat belt, although the latter part of the month was stormy and cold and but little work could be accomplished. It was generally unfavorable for seeding oats in the interior valley States and this work became much behind. Early seeded oats made fairly good progress in the Southwest, however, and improvement was noted in most other portions of the South.

Meadows and pastures showed general improvement in the Southeastern States and rain the latter part of the month greatly benefited grass lands in California, where severe drought had prevailed. There was considerable stormy weather in the Rocky Mountain districts which, together with the cold, was rather unfavorable for stock, but at the same time the precipitation was beneficial for the range, though more rain was needed in parts of the Southwest.

There was more or less damage to fruit in west Gulf districts about the 10th, and at the same time some slight frost damage was reported from the far northwestern States. There was considerable frost injury to early fruit also in Arizona, and to peaches and apricots in the north Pacific States during the week ending March 25. On the whole, however, the continued cool weather was favorable for fruit interests and no widespread harm had occurred at the close of the month. Trees were backward in budding out and blooming, which tended to lessen the danger of damage from frost. There was some damage to truck crops in the southeast by heavy rains, and low temperatures were very unfavorable for planting and replanting truck in the Southern States.

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, March, 1924

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	° F.	° F.		° F.			° F.		In.	In.		In.		In.
Alabama	51.4	−5.3	Selma	87	31	Valley Head	19	15	3.32	−2.38	Scottsboro	7.55	Bay Minette	0.90
Alaska														
Arizona	46.4	−4.9	Continental	90	1	Springerville	−3	15	1.79	+0.69	Natural Bridge	4.44	Yuma Evaporation Station.	0.01
Arkansas	46.6	−6.0	2 stations	84	[2] 29	Nail	5	10	3.27	−1.43	Marshall	6.03	Searcy	1.25
California	50.0	−1.8	Calexico	92	[2] 9	Helm Creek	−19	29	2.78	−1.22	Squirrel Inn	13.00	Indio	0.03
Colorado	26.6	−8.4	Las Animas	74	27	2 stations	−26	[2] 9	2.33	+1.02	Cumbres	11.20	Hartsel	0.53
Florida	61.1	−4.8	3 stations	92	[2] 7	Cottage Hill	25	15	5.79	+3.45	Melrose	13.70	Homestead	0.00
Georgia	52.4	−4.4	2 stations	89	[2] 29	2 stations	18	[2] 11	3.42	−1.47	St. George	9.30	Norcross	1.85
Hawaii														
Idaho	33.6	−2.3	Mountainhome	66	1	Warren	−20	16	0.80	−0.87	Preston	3.60	Deer Flat	0.04
Illinois	36.6	−3.6	Sparta	75	27	2 stations	6	10	2.65	−0.37	White Hall	4.14	Greenville	1.27
Indiana	36.4	−4.0	Vevay	78	[2] 29	Valparaiso	11	7	3.60	−0.13	Delphi	6.39	Evansville	1.76
Iowa	31.9	−1.4	Clarinda	72	27	Decorah	3	16	2.65	+0.88	Fayette	4.76	Centerville	1.26
Kansas	35.4	−8.3	3 stations	78	3	Leoti	−4	18	2.56	+1.13	Syracuse	5.82	Kismet (near)	0.77
Kentucky	41.5	−4.9	Jackson	81	29	Anchorage	14	16	3.05	−1.79	Greensburg	5.34	2 stations	1.82
Louisiana	56.0	−5.0	Schriever	89	31	2 stations	22	11	3.49	−1.02	Alexandria	6.90	Delta Farms	1.49
Maryland-Delaware	40.8	−1.2	2 stations	77	[2] 29	do	11	[2] 14	5.02	+1.37	Baltimore, Md	6.66	Aberdeen, Md	3.13
Michigan	28.6	−0.5	Morenci	63	29	Humboldt	−22	31	1.74	−0.30	Ironwood	4.77	Eagle Harbor	0.34
Minnesota	27.5	+1.4	Ada	60	23	2 stations	−13	[2] 8	1.16	−0.06	Canby	3.79	Sandy Lake Dam	0.10
Mississippi	51.9	−5.6	Hattiesburg	88	28	Louisville	20	15	4.16	−1.59	Louisville	7.39	Hernando	1.13
Missouri	38.4	−5.4	Caruthersville (2)	80	27	Macon	8	10	2.53	−0.47	Steffenville	4.35	Greenville	1.14
Montana	29.0	−1.5	Billings	58	1	Hebgen Dam	−22	18	1.20	+0.31	Adel	7.15	Kenilworth	T.
Nebraska	30.0	−5.5	Beatrice	78	28	Harrison	−13	9	1.69	+0.58	Guide Rock	3.79	Mitchell (near)	0.61
Nevada	36.7	−4.2	2 stations	79	[2] 2	2 stations	−3	[2] 24	0.99	+0.11	Austin	2.60	Lahonton	0.11
New England	32.4	+1.8	do	63	[2] 28	Van Buren, Me	−13	3	1.47	−2.27	Nantucket, Mass	4.43	2 stations	0.49
New Jersey	38.8	0.0	Pleasantville	76	30	Layton	5	2	2.51	−1.32	Tuckerton	5.69	Woodcliff Lake	0.80
New Mexico	38.9	−5.0	2 stations	85	[2] 25	Red River Canyon	−19	9	1.28	+0.46	Red River Canyon	5.23	2 stations	0.20
New York	31.9	+0.4	3 stations	66	[2] 28	Wanakena	−8	1	1.02	−2.08	Mohonk Lake	2.59	Chazy	T.
North Carolina	46.6	−3.1	do	84	[2] 30	Jefferson	6	11	2.72	−1.63	Highlands	5.35	Southport	0.92
North Dakota	25.5	+2.9	Amidon	58	1	Westhope	−20	6	0.44	−0.29	Fryburg	1.45	4 stations	T.
Ohio	36.2	−3.4	McArthur	83	29	Canfield	10	2	3.53	+0.07	Lancaster	6.10	Willoughby	1.18
Oklahoma	43.2	−8.8	2 stations	86	[2] 3	Kenton	1	17	3.30	+1.46	Meeker	5.34	Poteau	1.21
Oregon	40.7	−1.3	Echo	71	5	3 stations	2	[2] 8	1.58	−1.55	Government Camp	6.01	Harper	0.02
Pennsylvania	36.1	−0.9	2 stations	78	[2] 29	Wellsboro	3	[2] 1	2.83	−0.58	Somerset	8.97	Towanda	0.59
Porto Rico	75.0	+1.1	Mayaguez	97	25	Cayey	48	17	1.61	−1.93	Cepero	4.41	Mona Island	0.00
South Carolina	51.0	−3.9	2 stations	88	[2] 28	Santuck	19	17	2.74	−1.20	Parris Island	4.37	Conway	1.42
South Dakota	27.3	−2.6	8 stations	60	[2] 11	Elk Mountain	−15	8	1.48	+0.63	Marion	3.85	Cottonwood	0.32
Tennessee	44.1	−5.6	Dover	81	27	Crossville	14	8	3.09	−2.21	Loudon	5.08	Worsham	1.20
Texas	53.6	−5.3	Fort McIntosh	104	28	Romero	4	9	2.26	+0.28	Corsicana	5.75	2 stations	0.00
Utah	33.3	−5.7	Springdale	74	1	Winter Quarters	−13	31	1.80	+0.26	Silver Lake	7.64	Vernal	0.10
Virginia	43.2	−2.3	Hopewell	79	[2] 28	Mineral	11	3	4.02	+0.25	Warsaw	7.20	Speers Ferry	1.80
Washington	41.3	+0.3	Hanford	74	25	Paradise Inn	5	29	1.02	−2.00	Paradise Inn	9.10	3 stations	0.00
West Virginia	38.9	−3.9	Glenville	83	30	Cheat Bridge	4	7	4.16	+0.33	Bayard	7.86	Beckley	1.60
Wisconsin	27.6	−1.4	2 stations	61	27	Long Lake	−16	31	2.14	+0.39	Stevens Point	5.15	Solon Springs	0.33
Wyoming	22.9	−7.4	Torrington	61	27	Riverside	−30	8	1.60	+0.64	Basin	5.21	Eden	0.27

For description of tables and charts, see REVIEW, January, 1924, pp. 56–57.

[2] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1924*

Districts and stations	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with .01, or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							**34.4**	**+1.7**										**73**	**1.46**	**−2.4**										**5.3**		
Eastport	76	67	85	29.59	29.68	−.25	31.8	+2.9	47	24	37	15	16	27	22	29	25	75	1.13	−3.2	12	10,222	n.	48	ne.	12	6	5	20	7.2	9.3	T.
Greenville, Me	1,070	6		28.55	29.74		27.0		51	23	35	−2	2	19	39				1.36		10		ne.				11	6	14		13.5	22.0
Portland, Me	103	82	117	29.62	29.75	−.21	34.0	+2.2	54	28	40	16	2	28	24	30	24	71	0.89	−2.9	10	8,007	nw.	44	n.	11	10	11	10	5.3	4.5	0.0
Concord	288	70	79	29.42	29.73	−.27	33.7	+2.9	55	23	41	5	2	26	36				0.55	−2.8	5	5,858	nw.	27	ne.	21	18	6	7	4.2	1.5	0.0
Burlington	404	11	48	29.34	29.80	−.20	30.4	+3.1	50	23	37	2	2	24	32				0.75	−1.1	10	7,583	n.	37	s.	30	6	5	20	7.3	4.5	T.
Northfield	876	12	60	28.82	29.84	−.16	28.8	+2.6	50	23	37	−5	2	20	38	25	22	79	0.49	−2.3	7	6,223	n.	36	n.	12	6	5	20	7.2	2.6	T.
Boston	125	115	188	29.59	29.73	−.24	37.4	+1.8	59	28	43	21	16	32	23	32	24	62	2.04	−2.0	7	9,074	w.	41	ne.	11	11	12	8	5.0	7.4	0.0
Nantucket	12	14	90	29.68	29.69	−.29	35.8	−1.0	48	24	40	23	15	31	17	33	31	85	4.43	+0.4	9	13,812	nw.	72	ne.	11	16	3	12	4.6	7.6	0.0
Block Island	26	11	46	29.68	29.71	−.27	36.0	+0.6	53	24	40	23	15	31	21	33	29	79	1.56	−2.8	10	16,791	w.	72	ne.	12	16	5	10	4.5	3.7	0.0
Providence	160	215	251	29.56	29.74	−.24	36.2	+0.5	59	28	43	19	14	30	24	32	26	69	1.34	−3.3	9	12,098	nw.	53	nw.	16	16	6	9	4.3	10.4	0.0
Hartford	159	122	140	29.60	29.77	−.22	36.6	+1.6	60	28	44	20	2	29	25				1.46	−2.9	6		nw.				16	5	10	4.4	4.2	0.0
New Haven	106	74	153	29.64	29.76	−.23	37.3	+1.5	61	28	44	20	2	31	24	32	26	66	1.38	−3.1	8	8,741	n.	58	n.	12	18	3	10	4.7	3.2	0.0
Middle Atlantic States							**40.5**	**+0.1**										**69**	**3.14**	**−0.5**										**5.2**		
Albany	97	102	115	29.70	29.80	−.21	35.0	+2.3	56	23	42	18	14	28	30	30	25	70	0.63	−2.1	7	6,886	nw.	36	n.	11	15	7	9	4.4	0.8	0.0
Binghamton	871	10	84	28.84	29.79	−.23	33.0	+1.0	54	23	39	17	14	27	28				1.01	−1.6	11	5,782	nw.	33	sw.	30	3	13	15	7.3	2.9	0.0
New York	314	414	454	29.43	29.78	−.22	38.7	+1.0	65	28	46	23	15	32	28	33	28	68	1.65	−2.4	8	16,502	nw.	74	nw.	8	9	11	11	5.9	3.0	0.0
Harrisburg	374	94	104	29.42	29.83	−.22	39.0	+0.1	69	28	46	23	15	32	30	33	26	64	2.46	−0.7	8	5,471	nw.	36	w.	30	8	11	12	5.8	7.8	0.0
Philadelphia	114	123	190	29.67	29.80	−.22	41.6	+0.8	72	30	49	23	15	34	32	35	27	60	3.45	0.0	8	9,327	n.	40	e.	11	9	14	8	5.6	2.5	0.0
Reading	325	81	98	29.45	29.81		39.4		70	28	47	23	15	32	31	35	31	75	3.17	−0.4	9	5,618	nw.	33	n.	12	17	7	7	4.5	3.2	0.0
Scranton	805	111	119	28.94	29.82	−.20	35.8	+0.9	60	28	42	19	2	29	25	32	29	81	0.93	−2.2	8	6,856	nw.	38	sw.	30	5	13	13	6.5	6.9	0.0
Atlantic City	52	37	172	29.72	29.78	−.22	40.2	+1.6	73	30	47	24	15	33	33	35	31	74	3.59	−0.1	8	15,353	nw.	88	ne.	11	17	5	9	4.5	T.	0.0
Cape May	17	13	49	29.80	29.82	−.19	41.1	+0.3	68	30	48	26	14	34	28	36	33	78	4.90	+1.2	10	8,099	nw.	55	ne.	11	14	9	8	4.4	T.	0.0
Sandy Hook	22	10	55	29.75	29.77		38.5		64	30	44	25	15	33	26	33	27	68	1.81		9	15,125	nw.	70	ne.	11	13	9	9	5.1	0.1	0.0
Trenton	190	159	183	29.58	29.78		39.3		69	30	47	22	15	31	31	33	27	65	2.12	−1.9	9	11,461	nw.	56	nw.	8	15	7	9	4.9	3.2	0.0
Baltimore	123	100	113	29.67	29.81	−.22	43.0	+0.7	75	30	50	26	15	36	32	37	30	63	6.66	+2.8	12	5,350	nw.	32	ne.	11	12	10	9	5.3	11.6	0.0
Washington	112	62	85	29.70	29.82	−.22	42.6	0.0	76	30	50	26	15	35	31	36	29	62	6.17	+2.3	12	7,474	nw.	36	nw.	16	10	12	9	5.1	9.3	0.0
Cape Henry	18	8	54	29.78	29.80		45.5		79	30	52	30	3	38	34	41	37	79	3.38	−0.9	13	11,915	n.	53	nw.	12	16	5	10	4.6	0.2	0.0
Lynchburg	681	153	188	29.08	29.83	−.22	45.5	−1.8	74	28	55	25	11	36	42	38	31	62	2.77	−1.0	9	7,336	nw.	40	nw.	7	11	9	11	5.2	5.2	0.0
Norfolk	91	170	205	29.72	29.82	−.21	46.8	−1.4	76	29	55	29	11	38	32	40	33	66	3.16	−1.1	13	11,700	nw.	51	ne.	21	13	8	10	4.8	0.5	0.0
Richmond	144	11	52	29.67	29.83	−.21	45.6	−1.6	75	28	55	26	3	36	37	38	31	63	4.00	+0.3	11	7,811	sw.	39	nw.	12	15	10	6	4.4	3.7	0.0
Wytheville	2,304	49	55	27.46	29.88	−.17	39.5	−2.8	69	28	47	19	11	32	37	34	28	70	3.36	−1.1	12	6,515	w.	35	w.	7	11	6	14	5.8	9.6	0.0
South Atlantic States							**50.9**	**−2.8**										**70**	**3.44**	**−0.7**										**5.0**		
Asheville	2,255	70	84	27.51	29.91	−.15	42.1	−2.8	71	29	50	18	11	34	36	35	28	66	2.56	−1.4	12	8,633	nw.	36	nw.	26	11	8	12	5.5	4.2	0.0
Charlotte	779	55	62	29.03	29.87	−.18	48.6	−1.8	79	31	58	25	11	39	30	41	34	64	2.40	−2.2	15	5,150	nw.	30	w.	26	9	10	12	5.5	2.3	0.0
Hatteras	11	11	50	29.82	29.83	−.16	47.6	−4.4	66	4	54	30	11	41	23	44	40	79	3.52	−2.0	10	13,633	w.	66	sw.	11	12	8	11	5.1	T.	0.0
Manteo	12	5	42				46.2		78	30		28	11		36				3.02		7		s.				16	3	12		0.0	0.0
Raleigh	376	103	110	29.45	29.86	−.19	48.7	−1.5	79	29	57	25	11	40	31				2.08	−2.2	10	7,887	nw.	39	nw.	11	12	7	12	5.3	2.1	0.0
Wilmington	78	81	91	29.79	29.88	−.17	52.3	−1.0	78	31	61	29	11	43	32	45	40	72	2.70	−0.9	7	6,525	w.	46	nw.	20	15	3	13	4.9	T.	0.0
Charleston	48	11	92	29.85	29.90	−.16	54.0	−3.4	80	30	61	30	11	47	26	47	42	71	3.68	0.0	9	8,729	nw.	42	se.	20	11	6	14	5.3	0.0	0.0
Columbia, S. C	351	41	57	29.51	29.90	−.16	52.2	−3.0	81	31	62	27	11	43	35	45	39	68	2.90	−0.8	7	6,421	nw.	35	sw.	29	12	9	10	5.1	0.0	0.0
Due West	711	10	55	29.14	29.92		48.6		80	28	59	24	11	38	35				2.97		12	7,881	w.	40	w.	10	12	11	8	5.1	0.4	0.0
Greenville, S. C	1,039	113	122	28.77	29.87		48.4	−1.5	76	28	57	25	11	40	28	42	36	68	2.46		13	7,309	w.	47	w.	26	12	9	10	4.8	T.	0.0
Augusta	180	62	77	29.70	29.90	−.16	53.0	−3.0	84	28	63	28	11	43	34	46	41	70	2.89	−2.0	8	4,665	nw.	34	sw.	29	16	6	9	4.6	1.0	0.0
Savannah	65	150	194	29.85	29.92	−.14	55.3	−3.7	85	29	64	29	11	47	27	48	43	71	4.54	+0.9	9	11,116	nw.	48	se.	20	15	6	10	4.5	0.0	0.0
Jacksonville	43	209	245	29.89	29.94	−.12	58.2	−4.4	85	29	66	32	11	50	22	51	46	74	7.18	+3.7	11	10,142	nw.	46	sw.	29	14	8	9	4.6	0.0	0.0
Florida Peninsula							**66.1**	**−4.2**										**76**	**2.89**	**+0.6**										**4.6**		
Key West	22	10	64	29.94	29.96	−.09	69.6	−3.0	84	19	75	55	13	64	20	64	61	79	0.98	−0.5	5	9,048	nw.	37	nw.	10	14	10	7	4.1	0.0	0.0
Miami	25	71	79	29.95	29.98		66.8	−5.2	85	19	75	41	12	58	28	60	56	73	0.46	−2.2	3	7,141	nw.	32	sw.	14	11	11	9	4.9	0.0	0.0
Sand Key	23	39	72	29.94	29.97	−.08	69.0		82	30	72	56	16	66	12	64	61	77	0.77		6	12,734	n.	49	nw.	11	13	11	7	4.6	0.0	0.0
Tampa	35	79	87	29.92	29.96	−.11	62.0	−4.3	82	29	70	41	15	54	27	55	51	74	7.24	+4.4	11	5,608	w.	28	e.	17	10	13	8	5.0	0.0	0.0
East Gulf States							**53.2**	**−4.4**										**70**	**2.85**	**−2.9**										**5.4**		
Atlanta	1,174	190	216	28.67	29.92	−.14	48.9	−3.1	77	31	58	23	11	40	28	42	36	67	1.86	−3.9	8	10,608	nw.	48	nw.	1	13	4	14	5.5	4.0	0.0
Macon	370	78	87	29.53	29.93	−.13	52.4	−4.3	82	31	63	26	11	42	36	44	38	65	2.59	−2.9	8	5,833	nw.	28	nw.	11	11	6	14	5.6	2.0	0.0
Thomasville	273	49	58	29.65	29.94	−.12	56.4	−3.8	81	27	66	29	11	47	30	49	43	68	2.15	−2.9	12	4,431	nw.	27	sw.	29	11	6	14	5.7	0.0	0.0
Apalachicola	36	42	49	29.91	29.95		56.4		74	30	62	34	11	50	21	52	48	78	8.78		10	6,919	nw.	38	ne.	9	13	8	10	4.9	0.0	0.0
Pensacola	56	149	185	29.90	29.96	−.10	56.0	−4.3	74	29	62	31	11	50	20	51	48	78	2.87	−2.5	10	10,766	n.	78	s.	29	12	6	13	5.7	0.0	0.0
Anniston	741	9	57	29.17	29.97	−.09	48.0	−4.5	79	28	59	24	16	37	36				2.76	−3.0	11	5,447	nw.	34	e.	20	12	9	10	5.2	5.1	0.0
Birmingham	700	11	48	29.20	29.97	−.09	50.2	−5.2	78	30	60	25	11	40	35	42	36	66	4.10	−1.7	10	6,311	nw.	36	s.	28	12	5	14	5.4	6.5	0.0
Mobile	57	125	161	29.90	29.96	−.10	56.0	−4.0	80	31	64	31	11	48	26	50	46	76	1.07	−6.1	8	8,191	n.	36	s.	29	7	13	11	5.7	0.0	0.0
Montgomery	223	100	112	29.71	29.97	−.09	53.4	−4.4	82	31	63	29	11	44	30	46	40	65	3.25	−3.1	11	5,781	nw.	28	nw.	23	10	7	14	5.6	1.4	0.0
Corinth	469	6					47.3		77	28	56	26	11	39	33				2.86		9		nw.				4	16	11		T.	0.0
Meridian	375	85	93	29.56	29.97	−.08	52.0	−5.6	80	30	62	27	11	42	34	45	38	66	2.83	−2.8	11	5,553	ne.	30	se.	28	13	7	11	5.1	2.0	0.0
Vicksburg	247	65	73	29.71	30.00	−.04	53.2	−5.3	83	28	62	31	10	45	26	46	40	68	5.52	−0.7	9	6,373	ne.	27	nw.	10	12	7	12	4.9	2.0	0.0
New Orleans	53	76	84	29.90	29.96	−.08	58.7	−4.1	84	31	67	38	15	50	29	52	48	74	2.39	−2.9	6	6,010	n.	28	s.	28	10	8	13	5.6	0.0	0.0
West Gulf States							**53.1**	**−5.0**										**73**	**2.57**	**−0.5**										**5.6**		
Shreveport	249	77	93	29.70	29.97	−.04	53.3	−5.0	82	28	62	29	10	45	26	46	40	67	4.32	−0.2	9	5,951	nw.	29	s.	28	14	6	11	4.8	1.2	0.0
Bentonville	1,303	11	44				40.8	−6.5	74	27	49	17	10	32	32				4.17		13	4,765	nw.	36	sw.	29	12	7	12		20.0	0.0
Fort Smith	457	79	94	29.48	29.97	−.04	46.0	−6.6	78	27	54	25	10	38	32	40	33	65	1.96	−1.7	12	7,688	e.	61	sw.	29	11	6	14	5.9	2.4	0.0
Little Rock	357	136	144	29.59	29.97	−.06	47.3	−5.7	78	28	55	26	10	39	30	42	36	69	2.70	−2.2	9	7,634	e.	54	w.	28	11	7	13	5.7	6.6	0.0
Brownsville	57	53	61	29.82	29.88		65.6		84	30	73	39	10	58	25	60	57	81	0.12		4	7,244	s.	31	n.	13	1	20	10	6.6	0.0	0.0
Corpus Christi	20	11	73	29.91	29.93	−.05	62.0	−2.4	80	29	68	37	10	56	22	57	54	80	0.32	−1.5	10	10,147	n.	38	se.	3	6	3	22	7.2	0.0	0.0
Dallas	512	109	117	29.42	29.98		51.0		80	27	60	28	10	42	31				3.98		11	7,380	nw.	36	se.	16	11	10	10	5.1	4.3	0.0
Fort Worth	670	106	114	29.23	29.95	−.03	50.8	−5.8	86	27	60	28	9	42	34	45	39	67	4.66	+2.9	11	8,462	nw.	38	w.	28	11	7	13	5.5	6.0	0.0
Galveston	54	106	114	29.91	29.97	−.04	58.8	−3.6	78	30	64	37	10	54	22	54	51	81	1.43	−1.5	7	9,657	se.	44	nw.	13	10	12	9	5.3	0.0	0.0
Groesbeck	461	11	56	29.45	29.94		52.6		81	27	61	29	10	44	31				4.18		8	9,099	n.	51	nw.	28	10	7	14	5.8	0.0	0.0
Houston	138	111	121	29.80	29.95		59.0	−4.5	83	30	67	33	10	51	27				2.24		9	7,256	se.	37	se.	16	10	8	13	5.5	0.0	0.0
Palestine	510	64	72	29.43	29.97	−.03	53.0	−6.1	81	27	62	28	10	44	29	47	42	72	4.31	+0.8	7	6,866	n.	39	w.	28	11	7	13	5.5	T.	0.0
Port Arthur	34	58	66	29.91	29.95		57.9		80	30	65	33	10	51	23	52	47	75	1.71		9	8,305	se.	40	se.	28	12	9	10	5.1	0.0	0.0
San Antonio	693	119	132	29.20	29.93	−.05	58.6	−3.5	88	26	69	30	10	48	31	51	45	69	1.29	−0.4	10	7,196	ne.	40	nw.	13	10	13	8	5.0	0.0	0.0
Taylor	583	55	63	29.36	29.98	−.01	54.6	−5.1	83	26	64	28	10	45	31				2.14	−0.5	11	7,407	n.	34	nw.	28	9	10	12	5.9	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1924*—Continued

Districts and stations	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with .01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Ohio Valley and Tennessee							**40.1**	**−4.2**										**73**	**3.51**	**−0.9**										**7.3**		
Chattanooga	762	189	213	29.12	29.94	−.12	46.6	−4.6	76	29	55	23	11	38	31	40	32	62	4.59	−1.6	13	7,358	nw.	38	sw.	29	8	6	17	6.2	1.4	0.0
Knoxville	996	102	111	28.84	29.91	−.15	45.4	−3.2	75	29	54	22	10	37	34	39	33	67	3.98	−1.6	11	5,837	sw.	40	sw.	29	8	3	20	6.9	2.4	0.0
Memphis	399	76	97	29.54	29.97	−.07	46.0	−6.3	76	28	53	27	10	39	25	41	36	72	2.32	−3.4	9	5,446	nw.	39	sw.	29	7	13	11	6.0	T.	0.0
Nashville	546	168	191	29.38	29.97	−.08	43.5	−5.7	74	28	51	23	10	36	31	38	32	70	1.74	−3.7	12	8,879	nw.	46	sw.	29	10	6	15	6.3	0.8	T.
Lexington	989	193	230	28.84	29.93	−.12	39.1	−4.6	72	29	46	20	16	32	27				2.42	−2.3	10	10,926	nw.	66	sw.	29	9	3	19	6.9	2.4	0.0
Louisville	525	219	255	29.35	29.95	−.10	40.5	−4.9	71	29	47	23	10	34	32	36	30	68	2.96	−1.4	11	9,405	w.	64	s.	29	6	8	17	7.1	2.0	T.
Evansville	431	139	175	29.48	29.96	−.08	40.0	−5.9	69	27	47	23	10	34	32	36	31	72	1.76	−2.8	11	9,296	nw.	64	sw.	29	4	9	18	7.4	4.6	0.3
Indianapolis	822	194	230	29.02	29.93	−.11	35.6	−4.4	65	29	41	19	7	30	29	33	30	82	4.72	+0.7	14	9,721	n.	54	sw.	29	3	9	19	7.9	16.4	0.2
Royal Center	736	11	55	29.10	29.92		33.1		63	29	39	18	7	27	30				2.84		13	8,796	n.	44	w.	7	1	5	25	8.6	11.5	T.
Terre Haute	575	96	129	29.30	29.93		36.8		67	27	43	19	7	31	34	33	30	79	2.87		12	7,669	nw.	48	sw.	29	4	3	24	8.0	11.3	0.5
Cincinnati	628	11	51	29.23	29.92	−.13	37.7	−3.2	72	29	44	22	8	31	29		32	80	4.16	+0.5	12	6,603	sw.	45	sw.	29	4	6	21	7.6	6.7	0.0
Columbus	824	179	222	29.01	29.91	−.13	36.4	−2.7	71	29	43	20	15	30	26	33	29	78	4.28	+1.1	12	8,906	nw.	44	sw.	29	3	6	22	8.1	2.4	0.0
Dayton	899	137	173	28.93	29.90		36.6	−3.8	70	29	42	21	7	31	28	33	29	76	4.31	+0.9	15	7,870	nw.	52	sw.	29	3	7	21	7.6	7.8	0.0
Elkins	1,947	59	67	27.78	29.89	−.16	36.5	−3.5	75	29	45	14	9	28	38	32	28	77	4.41	+0.3	19	5,686	w.	39	sw.	30	2	14	15	7.6	12.4	0.0
Parkersburg	638	77	84	29.24	29.91	−.14	40.0	−2.8	81	29	48	24	14	32	30	34	30	74	3.37	−0.4	12	5,319	nw.	33	w.	7	6	7	18	7.0	3.0	0.0
Pittsburgh	842	353	410	28.96	29.88	−.16	37.0	−2.6	76	29	44	18	15	30	31	32	26	69	4.15	+1.1	14	9,717	nw.	44	sw.	30	0	14	17	7.9	17.8	0.0
Lower Lake Region							**32.4**	**−0.6**										**77**	**1.53**	**−1.1**										**7.4**		
Buffalo	767	247	280	29.02	29.87	−.15	31.2	+0.1	53	29	37	16	14	26	25	28	24	78	1.41	−1.2	12	12,795	w.	62	sw.	30	4	8	19	7.3	5.1	T.
Canton	448	10	61	29.31	29.80		28.8	+1.1	48	23	35	5	1	22	22				0.95	−1.9	11	8,379	w.	40	e.	12	11	8	12	5.2	6.2	0.5
Oswego	335	76	91		29.91	−.10	31.5	+1.2	46	5	36	16	14	27	16			79	0.49	−2.4	7	9,008	nw.	42	ne.	12	7	6	18		3.8	T.
Rochester	523	86	102	29.28	29.87	−.15	32.4	+0.6	52	23	38	16	14	27	24	29	24	73	1.10	−1.8	13	6,824	w.	39	w.	30	7	6	18	7.0	6.7	T.
Syracuse	597	97	113	29.18	29.83	−.19	31.8	+0.4	49	23	37	16	14	27	19				0.67	−1.7	14	8,802	nw.	37	s.	5	3	8	20	7.5	4.7	T.
Erie	714	130	166	29.09	29.88	−.14	32.7	−0.8	70	29	38	16	1	27	37	29	26	77	1.62	−1.0	12	9,374	nw.	46	sw.	30	3	9	19	7.5	8.4	0.0
Cleveland	762	190	201	29.05	29.89	−.14	33.0	−1.6	72	29	38	17	1	28	39	30	26	78	1.65	−1.1	12	9,092	nw.	48	s.	29	2	5	24	8.4	2.6	0.0
Sandusky	629	62	70	29.20	29.90	−.13	34.1	−1.0	69	29	39	19	15	29	35				2.93	+0.4	14	6,455	nw.	34	w.	27	3	4	24	8.2	5.9	0.0
Toledo	628	208	243	29.22	29.91	−.12	34.1	−1.2	66	29	40	18	15	28	33	30	27	76	2.60	+0.3	15	10,836	nw.	52	sw.	29	5	5	21	7.6	6.6	0.0
Fort Wayne	856	113	124	28.97	29.92		33.6	−5.3	64	29	39	20	15	28	29	31	28	83	3.41		15	7,139	n.	45	sw.	29	4	6	21	7.7	9.9	T.
Detroit	730	218	258	29.09	29.90	−.13	33.6	+0.2	56	27	39	19	15	28	26	30	25	73	1.93	−0.4	12	8,990	ne.	46	e.	29	5	4	22	7.7	7.5	0.0
Upper Lake Region							**29.3**	**+1.1**										**80**	**1.77**	**−0.5**										**6.9**		
Alpena	609	13	92	29.25	29.94	−.09	27.8	+2.3	50	27	34	5	1	22	29	25	22	80	1.16	−0.9	8	9,052	nw.	42	ne.	29	5	13	13	6.5	9.3	4.0
Escanaba	612	54	60	29.31	30.00	−.04	26.7	+2.5	51	27	34	2	31	20	24	24	21	82	1.20	−0.8	7	8,469	n.	46	n.	30	9	11	11	5.7	13.3	5.5
Grand Haven	632	54	89	29.22	29.92	−.11	30.9	−0.8	47	27	36	13	15	25	18	28	24	78	2.40	−0.1	13	7,599	n.	37	w.	6	6	5	20	7.1	9.6	0.0
Grand Rapids	707	70	87	29.14	29.94	−.09	32.2	−0.8	55	27	38	14	15	26	22	28	25	77	2.08	−0.4	15	4,731	e.	24	e.	29	6	6	19	7.3	8.7	0.0
Houghton	668	62	99	29.28	30.03	−.01	26.2	+3.4	43	26	32	11	30	20	26				0.95	−1.2	12	6,818	w.	46	ne.	29	6	10	15	7.1	9.0	5.0
Lansing	878	11	62	28.94	29.90		31.2	−0.1	56	27	38	12	1	24	27	28	25	81	1.78	−0.5	14	4,748	ne.	20	ne.	20	3	9	19	7.5	9.8	0.0
Ludington	637	60	66	29.22	29.94	−.16	29.5		44	22	34	12	31	24	19	27	24	82	2.06		11	6,882	n.	30	e.	29	5	9	17	6.8	12.9	2.0
Marquette	734	77	111	29.21	30.04	−.14	27.7	+4.0	48	27	32	10	31	23	19	25	21	79	2.80	+0.7	12	7,062	nw.	26	nw.	27	2	6	23	7.8	28.0	10.0
Port Huron	638	70	120	29.18	29.89		30.9	+0.5	51	27	36	10	1	26	23	28	26	83	0.81	−1.6	9	8,683	nw.	38	w.	7	3	14	14	6.8	3.2	T.
Saginaw	641	69	77	29.21	29.92		30.2	−1.3	55	27	36	9	1	24	24	28	25	82	1.11	−1.5	9	6,428	nw.	26	ne.	20	3	8	20	8.0	2.8	0.1
Sault Sainte Marie	614	11	52	29.26	29.98	−.05	26.2	+4.6	47	21	33	1	31	19	26	23	20	81	0.89	−1.0	6	6,834	nw.	35	nw.	28	7	11	13	6.1	8.9	2.0
Chicago	823	140	310	29.04	29.95	−.08	34.6	−1.7	63	27	39	17	7	30	26	31	27	76	3.70	+1.2	15	8,733	n.	40	w.	7	4	6	21	7.8	11.5	0.1
Green Bay	617	109	144	29.27	29.96	−.08	28.2	+1.4	52	27	35	11	15	22	26	25	23	82	2.49	+0.1	14	8,434	n.	53	ne.	29	7	8	16	6.4	24.1	7.6
Milwaukee	681	125	139	29.19	29.95	−.08	31.8	−0.3	58	27	37	17	8	27	24	29	25	80	2.94	+0.3	16	8,577	n.	31	ne.	20	7	4	20	7.4	17.1	0.3
Duluth	1,133	11	47	28.78	30.05	−.01	25.3	+1.6	44	27	32	2	30	18	27	22	18	80	0.42	−1.1	9	8,450	ne.	56	ne.	29	13	8	10	5.1	4.1	T.
North Dakota							**26.2**	**+4.1**										**76**	**0.48**	**−0.5**										**6.7**		
Moorhead	940	50	58	29.02	30.08	.00	27.4	+4.7	50	26	35	5	10	20	30	24	19	74	0.25	−0.9	7	5,613	n.	33	nw.	6	10	11	10	5.8	1.4	0.0
Bismarck	1,674	8	57	28.28	30.13	+.08	26.8	+2.6	51	24	36	2	10	18	31	23	18	74	0.58	−0.5	4	6,541	e.	32	nw.	5	5	10	16	6.5	5.2	0.9
Devils Lake	1,478	11	44	28.47	30.10	+.05	24.2	+5.7	46	26	32	−1	10	16	26	21	18	81	0.42	−0.6	8	6,902	ne.	42	n.	5	5	7	19	7.1	5.6	0.0
Ellendale	1,457	10	56	28.47	30.08		26.8		53	26	36	4	8	17	30				0.76		8	9,689	nw	44	ne.	29	4	8	19	7.2	6.3	T.
Grand Forks	835	12	89				26.8		47	23	34	3	10	19	31				0.31		7		n.	33	n.	6	13	9	9		5.4	T.
Williston	1,878	41	48	28.02	30.07	+.03	26.4	+3.5	46	24	34	−2	8	19	29	23	19	75	0.68	0.0	9	6,071	se.	27	e.	28	5	11	15	6.8	6.4	0.0
Upper Mississippi Valley							**34.2**	**−2.2**										**78**	**2.58**	**+0.2**										**7.4**		
Minneapolis	918	102	208	29.00	30.01		29.8		50	6	36	3	31	24	21				1.23	−0.4	8	8,151	ne.	44	ne.	29	0	10	21	8.1	12.6	12.0
St. Paul	837	236	261	29.08	30.01	−.04	30.4	+1.3	48	28	37	6	31	24	21				2.83	+1.2	9	8,013	nw.	45	ne.	29	4	12	15	6.9	19.1	16.0
La Crosse	714	11	48	29.19	29.98	−.06	30.0	−1.5	55	27	37	9	31	23	29				3.23	+1.6	11	3,693	n.	16	n.	29	4	6	21	7.7	17.5	5.4
Madison	974	70	78	28.90	29.99	−.05	29.0	−1.6	56	27	34	12	15	24	22	26	24	83	2.84	+0.6	15	6,849	n.	32	ne.	20	4	7	20	7.8	18.7	0.7
Wausau	1,247	4		28.61	30.00		26.0		45	27	34	2	31	18	29				3.13		11		nw.				11	3	17	6.0	31.7	13.0
Charles City	1,015	10	49	28.89	30.00	−.05	29.2	+0.8	55	27	36	10	8	23	24	26	24	83	3.27	+1.4	8	4,914	n.	22	ne.	28	4	12	15	7.0	14.0	1.6
Davenport	606	71	79	29.28	29.96	−.07	34.2	−1.9	66	27	40	16	7	28	28	32	29	82	2.71	+0.5	12	5,752	nw.	28	e.	29	4	6	21	7.7	6.0	0.3
Des Moines	861	84	97	29.05	29.98	−.06	33.2	−2.7	68	27	39	15	31	27	32	30	26	77	3.10	+1.4	10	5,506	nw.	24	e.	29	5	8	18	7.5	7.0	1.4
Dubuque	700	81	96	29.22	30.00	−.04	32.0	−2.0	62	27	37	15	7	27	26	29	25	76	2.85	+0.6	13	5,007	nw.	22	e.	29	4	7	20	7.7	10.1	T.
Keokuk	614	64	78	29.28	29.98	−.05	36.2	−2.7	68	27	43	15	10	29	31	32	26	70	1.96	−0.4	10	6,679	n.	56	sw.	29	4	3	24	7.9	7.1	T.
Cairo	358	87	93	29.57	29.96	−.08	42.0	−5.0	71	28	49	22	10	35	26	37	32	71	1.28	−2.7	10	8,193	nw.	60	sw.	28	5	10	16	7.1	2.0	T.
Peoria	609	11	45	29.28	29.96	−.07	34.8	−2.2	66	27	41	18	10	28	31	32	30	84	2.28	−0.7	14	5,760	nw.	35	sw.	29	7	3	21	7.3	7.9	T.
Springfield, Ill	636	10	91	29.25	29.94	−.09	36.8	−3.4	68	27	43	15	10	31	31	33	30	80	2.79	−0.3	12	6,847	nw.	34	sw	29	4	6	21	7.7	8.7	0.1
Hannibal	534	74	109	29.37	29.95	−.07	37.2	−3.8	69	27	44	16	10	30	31				2.57	−0.2	14	7,197	nw.	52	sw.	29	3	9	19	7.6	11.2	0.1
St. Louis	568	265	303	29.34	29.96	−.07	39.8	−4.0	72	27	46	21	10	34	29	35	29	70	3.24	−0.2	12	10,270	nw.	64	sw.	29	4	9	18	7.2	15.8	0.1
Missouri Valley							**33.6**	**−3.8**										**75**	**1.88**	**0.0**										**6.5**		
Columbia, Mo	784	11	84	29.10	29.96	−.03	37.8	−4.8	72	27	45	15	10	30	31				1.81	−1.2	12	7,323	nw.	42	sw.	29	7	3	21	7.4	8.9	T.
Kansas City	963	161	181	28.93	29.99	−.02	37.8	−4.9	72	27	45	19	7	30	36	34	28	72	2.08	−0.7	10	9,263	nw.	46	w.	29	7	12	12	6.1	10.4	0.0
St. Joseph	967	11	49	28.92	29.98		36.8		72	27	45	18	31	29	36	32	27	74	2.42		11	7,377	nw.	44	nw.	29	7	11	13	6.3	10.1	0.0
Springfield, Mo	1,324	98	104	28.54	29.98	−.04	38.3	−6.9	72	27	46	16	10	30	31	34	29	75	2.77	−1.3	9	8,848	nw.	58	sw.	29	9	11	11	5.4	10.1	T.
Iola	984	11	50	28.91	29.98	−.03	39.0	−3.4	72	27	48	17	10	31	37				1.57	−0.8	10	6,096	nw.	36	w.	29	8	9	14	6.3	7.5	0.0
Topeka	987	92	107				37.4	−5.2	71	27	45	17	9	30	35				2.28	0.0	9	7,981	nw.	41	w.	29	6	15	10	6.0	13.1	0.0
Drexel	1,299	10	54	28.57	29.99		31.9		66	27	40	9	31	24	34				1.55		9	7,372	n.	38	w.	25	5	6	20	7.3	10.2	1.0
Lincoln	1,189	11	84	28.71	30.02	.00	34.4	−3.1	71	28	42	15	31	27	32	30	27	79	1.27	−0.1	9	7,552	nw.	49	nw.	29	5	6	20	7.5	9.2	0.0
Omaha	1,105	115	122	28.80	30.02	−.02	33.8	−3.2	69	27	40	12	31	27	30	30	25	73	1.93	+0.5	11	6,971	nw.	38	nw.	29	6	8	17	6.9	10.5	T.
Valentine	2,598	47	54	27.24	30.05	+.02	25.9	−6.4	61	27	34	−1	7	18	33	23	19	78	1.73	+0.5	15	6,247	w.	38	nw.	25	5	9	17	6.6	19.0	T.
Sioux City	1,135	94	164	28.79	30.04	−.01	31.4	−1.3	59	27	37	8	31	26	27	28	23	75	1.82	+0.6	10	7,979	nw.	40	e.	28	8	4	19	6.9	11.1	3.6
Huron	1,306	59	74	28.64	30.09	+.03	28.4	−0.5	55	26	36	2	31	20	28	25	20	75	1.52	+0.5	10	6,299	nw.	39	n.	29	12	8	11	5.4	15.2	9.0
Pierre	1,572	70	75	28.35	30.07	+.02	29.2	−2.3	54	26	37	0	31	22	28	26	22	78	1.40	+0.1	6	6,059	e.	40	w.	26	6	7	18	6.5	15.4	1.0
Yankton	1,233	49	57	28.68	30.04	−.01	29.7	−3.5	57	26	36	7	31	23	27				2.43	+1.3	10	5,496	nw.	28	e.	28	7	8	16	6.7	11.9	3.5

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1924*—Continued

Districts and stations	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to means of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In	In.	In.	° F.	° F.	°F		°F	° F.		°F	° F.	° F.	° F.	%	In.	In.		Miles.								0–10	In.	In.
Northern Slope							**27.0**	**−4.4**										**74**	**1.41**	**+0.3**										**6.8**		
Billings	3,140	5					30.2		58	1	39	8	18	22	33				1.91		16		ne.				7	7	17		16.2	0.0
Havre	2,505	11	44	27.31	30.02	+.02	28.0	+0.9	49	1	36	2	8	20	28	26	23	83	1.01	+0.5	13	4,780	e.	24	sw.	25	9	6	16	6.1	10.1	0.0
Helena	4,110	87	112	25.69	29.98	−.03	31.0	−1.4	50	1	38	11	18	24	28	27	21	68	1.02	+0.3	16	6,068	sw.	37	sw.	5	1	6	24	8.2	15.4	0.0
Kalispell	2,973	48	56	26.84	29.95	−.04	34.1	+1.2	48	1	41	18	17	27	27	29	22	64	0.74	−0.3	10	3,699	nw.	25	sw.	29	4	12	15	6.4	4.5	0.0
Miles City	2,371	48	55	27.46	30.09	+.07	29.0	+0.4	51	1	35	8	8	23	25	26	22	76	1.00	+0.2	10	4,606	e.	24	w.	26	5	6	20	7.0	9.8	T.
Rapid City	3,259	50	58	26.55	30.10	+.09	24.7	−7.9	54	1	33	−1	7	17	30	22	16	70	1.73	+0.7	14	5,445	se.	30	nw.	5	5	11	15	7.0	17.6	1.0
Cheyenne	6,088	84	101	23.80	29.97	+.01	21.6	−11.5	50	1	30	−3	17	13	27	20	16	79	1.71	+0.8	14	9,333	w.	44	nw.	28	6	9	16	6.7	20.0	T.
Lander	5,372	60	68	24.48	29.98	−.01	23.4	−9.0	50	6	33	0	18	14	34	21	16	73	2.33	+0.7	10	3,270	w.	36	w.	29	6	12	13	6.1	26.8	5.0
Sheridan	3,790	10	47	26.02	30.05		23.2		50	1	33	−8	8	13	33	22	17	75	1.99		16	4,087	nw.	29	nw.	4	7	5	19	6.9	20.1	T.
Yellowstone Park	6,200	11	48	23.69	29.97	−.05	22.1	−4.5	43	6	32	−2	18	13	34	19	14	73	1.21	−1.0	22	5,501	nw.	29	nw.	14	3	17	11	6.5	13.9	12.6
North Platte	2,821	11	51	27.03	30.06	+.06	29.0	−7.6	68	27	38	1	9	20	38	25	21	77	1.93	+1.1	16	5,489	n.	36	n.	28	6	9	16	6.8	17.7	0.0
Middle Slope							**34.7**	**−8.6**										**73**	**2.38**	**+0.9**										**5.9**		
Denver	5,292	106	113	24.56	29.96	+.01	28.0	−11.3	59	27	36	2	9	20	30	24	20	77	1.29	+0.3	14	5,877	s.	35	nw.	4	7	11	13	6.4	20.7	T.
Pueblo	4,685	80	86	25.12	29.90	−.02	31.8	−9.8	66	27	43	−5	17	20	39	27	19	66	1.20	+0.3	7	5,572	e.	46	w.	28	6	15	10	6.0	12.1	0.0
Concordia	1,392	50	58	28.48	29.99	−.02	35.2	−5.8	72	28	44	14	18	27	35	30	25	71	2.56	+1.1	9	6,006	nw.	44	nw.	29	7	11	13	6.4	20.3	0.0
Dodge City	2,509	11	51	27.35	30.02	+.05	33.6	−9.2	70	3	43	6	18	24	37	30	26	80	2.77	+1.9	12	7,927	nw.	40	nw.	29	11	5	15	5.7	24.3	0.0
Wichita	1,358	139	158	28.52	29.98	−.01	37.6	−7.5	70	3	46	16	10	30	34	33	27	71	2.61	+0.4	12	9,994	n.	64	nw.	29	8	11	12	6.0	15.1	0.0
Broken Arrow	765	11	52	29.14	29.97		41.6		71	27	50	20	10	34	31				3.40		15	10,520	n.	64	sw.	29	15	3	13	5.3	17.3	0.0
Muskogee	652	4					44.2		77	27	54	23	11	35	39				5.28		12		nw.				10	11	10		17.3	0.0
Oklahoma City	1,214	10	47	28.68	29.99	+.01	41.8	−8.2	75	27	50	19	10	34	36	36	30	71	3.83	+1.4	11	8,501	n.	59	w.	29	13	5	13	5.4	20.7	0.0
Southern Slope							**48.8**	**−4.8**										**61**	**1.20**	**+0.2**										**4.2**		
Abilene	1,738	10	52	28.11	29.93	−.03	50.2	−4.7	86	27	62	22	10	39	35	41	33	61	2.15	+0.8	9	9,078	s.	44	w.	28	12	8	11	4.9	3.0	0.0
Amarillo	3,676	10	49	26.15	29.94	−.01	38.9	−6.1	78	27	50	11	9	28	38	33	28	74	1.75	+1.1	10	8,855	n.	49	sw.	28	17	8	6	4.5	15.1	0.0
Del Rio	944	64	71	28.93	29.92	−.03	59.5	−4.0	96	28	69	34	10	50	34				0.55	−0.6	7	8,581	se.	50	w.	28	15	10	6	4.3	0.0	0.0
Roswell	3,566	75	85	26.21	29.83	−.07	46.8	−4.5	81	27	61	18	9	32	44	36	22	47	0.36	−0.3	4	8,012	s.	54	sw.	28	21	6	4	3.1	1.6	0.0
Southern Plateau							**46.1**	**−4.7**										**47**	**0.64**	**+0.1**										**2.9**		
El Paso	3,762	110	133	26.05	29.81	−.07	51.6	−4.3	77	26	64	29	9	39	36	39	22	37	0.41	0.0	4	10,161	w.	53	w.	28	17	14	0	3.1	T.	0.0
Santa Fe	7,013	38	53	23.03	29.81	−.08	33.7	−6.0	58	27	44	9	9	23	31	27	17	55	1.12	+0.4	13	6,023	se.	35	sw.	29	12	10	9	4.8	9.6	0.0
Flagstaff	6,907	10	59	23.15	29.78	−.13	30.6	−5.3	60	1	43	4	31	19	39	25		63	2.40		8		s.	36	s.	2	11	15	5		24.8	2.0
Phoenix	1,108	11	81	28.70	29.86	−.05	56.6	−4.1	81	1	70	37	13	43	38	45	32	46	0.99	+0.5	4	4,466	e.	39	w.	12	22	5	4	2.4	0.0	0.0
Yuma	141	9	54	29.74	29.88	−.06	59.3	−4.8	84	1	74	36	22	45	39	47	32	41	0.03	−0.3	3	4,861	w.	30	nw.	15	26	4	1	1.4	0.0	0.0
Independence	3,957	5	25	25.85	29.90	−.04	44.6	−3.9	71	13	58	23	25	31	40	34	17	38	0.63	+0.1	3	8,411	nw.	48	nw.	15	20	10	1	2.6	1.3	0.0
Middle Plateau							**35.9**	**−5.0**										**59**	**1.51**	**+0.3**										**6.0**		
Reno	4,532	74	81	25.36	29.94	−.04	38.3	−2.7	66	1	50	19	8	27	41	31	21	54	0.96	+0.1	8	5,787	w.	46	w.	20	11	7	13	5.3	8.2	0.0
Tonopah	6,090	12	20	23.89	29.87		33.4		55	14	42	19	12	25	29				1.25		10		nw.									
Winnemucca	4,344	18	56	25.51	29.94	−.07	35.7	−4.3	62	1	48	14	22	24	37	29	21	59	0.58	−0.4	8	6,074	sw.	36	nw.	29	9	8	14	6.2	5.0	0.0
Modena	5,479	10	43	24.44	29.86	−.10	30.6	−7.6	56	1	44	9	22	17	42	25	17	62	2.84	+1.5	11	7,313	w.	50	n.	7	15	7	9	4.6	31.9	0.6
Salt Lake City	4,360	163	203	25.48	29.89	−.09	36.6	−5.1	60	2	43	21	31	30	27	31	24	61	2.21	+0.2	12	5,089	nw.	34	w.	28	4	8	19	7.4	19.6	0.0
Grand Junction	4,602	60	68	25.20	29.78	−.16	38.4	−5.2	64	2	48	18	17	29	30	32	22	57	0.94	+0.2	10	5,328	se.	37	w.	29	6	11	14	6.6	5.4	0.0
Northern Plateau							**39.2**	**−2.0**										**60**	**0.56**	**−1.0**										**6.3**		
Baker	3,471	48	53	26.36	29.99	−.04	35.2	−0.3	53	5	44	20	30	26	30	30	23	64	0.37	−1.1	8	5,156	se.	30	nw.	14	7	14	10	5.9	2.9	0.0
Boise	2,739	78	86	27.08	29.97	−.06	39.0	−3.7	60	1	49	20	30	29	29	33	23	55	0.30	−1.1	5	4,530	nw.	28	n.	14	10	9	12	5.5	1.6	0.0
Lewiston	757	40	48	29.19	30.01	−.02	43.4	−2.0	60	5	54	26	17	33	31				0.35	−0.9	6	2,748	e.	29	nw.	26	2	8	21	7.9	T.	0.0
Pocatello	4,477	60	68	25.31	29.90	−.11	33.4	−4.0	59	2	42	14	5	25	31	28	20	65	1.38	−0.4	10	6,747	se.	35	sw.	7	8	9	14	6.3	13.6	0.0
Spokane	1,929	101	110	27.91	29.99	−.02	39.6	−0.1	56	5	48	24	30	31	27	34	26	60	0.32	−1.2	7	4,431	sw.	24	n.	14	5	13	13	6.5	0.5	0.0
Walla Walla	991	57	65	28.92	30.00	−.02	44.4	−1.7	60	12	53	28	23	36	25	39	30	58	0.62	−1.3	9	4,333	s.	29	w.	28	9	13	9	5.6	T.	0.0
North Pacific Coast Region							**44.8**	**−0.4**										**78**	**1.55**	**−3.0**										**6.6**		
North Head	211	11	56	29.85	30.08	+.07	44.6	−0.6	58	1	49	34	28	40	19	42	39	83	2.43	−2.8	19	10,284	nw.	60	nw.	28	8	7	16	6.3	0.1	0.0
Port Angeles	29	8	53		30.07		43.4		58	17	51	31	28	36	22				0.83	−1.4	9	4,776	s.	35	nw.	14	8	15	8		0.6	0.0
Seattle	125	215	250	29.95	30.08	+.09	44.4	−0.5	56	13	50	32	29	38	21	40	35	71	0.42	−2.5	11	6,006	s.	54	sw.	28	4	11	16	7.0	T.	0.0
Tacoma	213	113	120	29.85	30.06	+.06	43.8	−0.4	58	31	51	30	29	37	22				0.77	−3.2	11	5,885	s.	37	sw.	28	5	10	16	7.0	T.	0.0
Tatoosh Island	86	9	57	29.96	30.06	+.10	44.6	+1.7	54	15	48	35	28	41	13	43	42	90	3.13	−5.4	17	9,136	e.	51	w.	28	8	9	14	6.2	T.	0.0
Yakima	1,071	5																														
Medford	1,425	4					43.4		64	13	55	23	18	32	39	39	37	77	0.74		13						1	6	24	6.3	0.0	0.0
Portland, Oreg.	153	68	106	29.91	30.07	+.05	45.8	−1.1	60	18	54	32	8	38	24	42	38	75	1.40	−3.3	14	4,020	nw.	30	w.	28	1	12	18	7.8	T.	0.0
Roseburg	510	9	57	29.54	30.10	+.06	45.6	−1.5	63	26	55	29	18	36	32	41	36	74	1.84	−2.1	18	2,478	n.	21	sw.	19	9	14	8	5.3	T.	0.0
Middle Pacific Coast Region							**51.4**	**−0.9**										**67**	**1.79**	**−2.2**										**3.8**		
Eureka	62	73	89	30.02	30.10	+.04	46.6	−1.7	60	31	52	33	25	41	19	44	40	80	2.85	−4.1	14	6,676	n.	42	n.	17	10	10	11	5.4	0.0	0.0
Point Reyes	490	7	18	29.42	29.93		49.0	−0.6	60	14	53	39	23	45	14				0.67		8	19,414	nw.	82	nw.	16	21	4	6	3.3	0.0	0.0
Red Bluff	332	50	56	29.61	29.97	−.07	53.8	+0.2	78	14	64	36	23	44	33	45	33	52	1.09	−2.7	6	6,352	nw.	37	nw.	15	20	6	5	3.2	0.0	0.0
Sacramento	69	106	117	29.88	29.96	−.07	52.8	−1.5	73	14	63	36	21	43	28	46	40	66	1.19	−1.8	7	6,884	nw.	38	nw.	7	17	9	5	3.4	0.0	0.0
San Francisco	155	208	243	29.81	29.98	−.08	54.5	+0.3	72	12	61	43	24	48	21	48	42	69	1.96	−1.2	8	7,648	w.	42	n.	15	21	3	7	3.3	0.0	0.0
San Jose	141	12	110	29.83	29.98		51.8	−1.9	78	14	64	33	21	39	38				1.87	−1.1	9	5,217	nw.	33	nw.	20	16	3	12	4.4	0.0	0.0
South Pacific Coast Region							**55.0**	**−0.9**										**65**	**3.19**	**+0.6**										**3.8**		
Fresno	327	89	98	29.60	29.96	−.05	54.4	−0.6	79	1	65	37	21	44	31	46	36	57	2.89	+1.1	8	5,045	nw.	36	nw.	15	18	7	6	3.5	0.0	0.0
Los Angeles	338	159	191	29.58	29.95	−.07	56.4	−1.1	75	31	64	43	21	48	25	49	42	65	3.42	+0.4	9	4,915	sw.	28	sw.	20	18	11	2	3.4	0.0	0.0
San Diego	87	62	70	29.87	29.96	−.06	56.6	−0.1	71	31	63	46	21	50	22	50	45	70	2.41	+0.7	11	6,087	w.	35	sw.	21	10	14	7	4.8	0.0	0.0
San Luis Obispo	201	32	40	29.77	30.00	−.08	52.8	−1.9	75	12	64	33	22	42	36	50	45	69	4.05	+0.1	11	3,614	nw.	23	w.	21	17	10	4	3.4	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	29.89	29.98		76.3	+0.9	89	15	82	66	26	70	20				0.46	−2.7	5	7,451	s.	30	e.	31	15	11	5	4.2	0.0	0.0
Panama Canal																																
Balboa Heights	118	7	97	29.71	29.84	−.03	81.5	+0.2	96	19	90	70	12	73	24	74	72	83	0.07	−0.6	3	6,791	nw.	31	n.	2	5	26	0	5.4	0.0	0.0
Colon	36	7	97	29.82	29.86	−.02	81.7	+1.2	92	21	87	73	18	77	15	75	73	80	0.71	−0.8	8	8,809	n.	25	n.	2	4	22	5	5.8	0.0	0.0
Alaska																																
Juneau	80	11	54				36.8		52	24	41	16	28	32	20	34	30	79	7.46		24	6,178	s.	38	e.	27	3	3	25	8.7	3.3	1.3

TABLE II.—*Data furnished by the Canadian Meteorological Service, March, 1924*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Mean maximum	Temperature of the air: Mean minimum	Temperature of the air: Highest	Temperature of the air: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	*In.*	*In.*	*In.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*In.*	*In.*	*In.*
St. Johns, N. F	125												
Sydney, C. B. I	48	29.54	29.59	−.29	30.9	+4.7	35.9	25.9	43	14	4.69	−0.24	17.5
Halifax, N. S	88	29.48	29.59	−.35	33.4	+4.4	39.3	27.5	49	14	2.82	−2.64	3.3
Yarmouth, N. S	65	29.51	29.58	−.37	32.9	+2.1	38.2	27.7	49	18	2.40	−2.45	15.4
Charlottetown, P. E. I	38	29.57	29.61	−.29	30.1	+4.7	35.4	24.8	43	13	1.47	−1.74	13.1
Chatham, N. B	28	29.58	29.61	−.29	27.8	+4.8	35.0	20.6	46	−7	2.74	−0.73	24.3
Father Point, Que	20	29.74	29.76	−.14	24.0	+3.7	29.9	18.2	39	2	1.63	−1.10	16.1
Quebec, Que	296	29.45	29.78	−.18	28.3	+7.1	33.5	23.1	46	9	0.95	−2.31	9.4
Montreal, Que	187	29.58	29.80	−.20	30.1	+6.3	35.5	24.7	46	9	1.83	−1.96	14.0
Ottawa, Ont	236	29.56	29.84	−.17	30.6	+9.1	38.0	23.2	56	5	1.01	−1.71	7.6
Kingston, Ont	285	29.51	29.83	−.18	31.0	+5.4	37.2	24.8	53	2	0.80	−1.84	1.3
Toronto, Ont	379	29.45	29.88	−.14	31.6	+4.3	37.2	26.0	51	10	0.78	−1.86	2.7
Cochrane, Ont	930												
White River, Ont	1,244	28.63	29.99	−.04	17.8	+5.6	29.9	5.7	42	−17	0.18	−1.20	1.8
Port Stanley, Ont	592												
Southampton, Ont	656	29.15			28.0	+3.3	34.0	22.1	46	2	1.17	−1.48	7.4
Parry Sound, Ont	688	29.16	29.87	−.15	27.0	+5.9	34.3	19.7	47	−10	1.01	−1.22	6.8
Port Arthur, Ont	644	29.33	30.06	+.01	24.8	+8.0	32.7	17.0	41	−3	0.22	−0.75	2.2
Winnipeg, Man	760												
Minnedosa, Man	1,690	28.25	30.14	+.08	20.0	+7.5	29.4	10.5	40	−7	0.16	−0.49	1.6
Le Pas, Man	860				15.0		27.9	2.1	41	−18	0.40		4.0
Qu'Appelle, Sask	2,115	27.74	30.06	+.02	23.0	+8.1	31.2	14.8	40	−11	1.98	+1.21	19.8
Medicine Hat, Alb	2,144												
Moose Jaw, Sask	1,759				26.2		33.0	19.4	42	−1	0.57		5.7
Swift Current, Sask	2,392	27.39	30.10	+.08	25.1	+3.1	32.8	17.4	41	0	0.43	−0.38	4.2
Calgary, Alb	3,428												
Banff, Alb	4,521												
Edmonton, Alb	2,150												
Prince Albert, Sask	1,450	28.52	30.16	+.08	22.2	+10.2	31.4	12.9	40	−8	0.32	−0.45	4.1
Battleford, Sask	1,592	28.29	30.10	+.04	22.3	+9.2	32.7	12.0	41	−13	0.13	−0.33	2.5
Kamloops, B. C	1,262												
Victoria, B. C	230	29.80	30.06	+.09	45.0	+3.1	51.1	38.9	57	31	0.61	−2.51	0.1
Barkerville, B. C	4,180												

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Winnipeg, Man	760	29.38	30.17	+.07	12.0	+13.6	22.0	2.1	46	−22	0.41	−0.57	4.1
Medicine Hat, Alb	2,144	27.74	30.05	.00	30.8	+19.6	40.6	21.1	61	−12	0.25	−0.42	2.5
Calgary, Alb	3,428	26.43	30.12	+.13	27.8	+14.3	40.5	15.1	59	−18	1.10	+0.47	11.0
Banff, Alb	4,521	25.39	30.12	+.14	25.1	+5.9	35.7	14.5	47	−10	2.27	+1.35	15.6
Kamloops, B. C	1,262	28.80	30.13	+.17	38.4	+10.1	45.3	31.6	60	23	0.28	−0.51	0.7
Barkerville, B. C	4,180	25.59	29.97	+.06	26.5	+7.6	33.8	19.3	43	4	3.71	+0.65	37.0

SEISMOLOGICAL REPORTS FOR MARCH, 1924

W. J. HUMPHREYS, Professor in Charge

[Weather Bureau, Washington, May 3, 1924]

TABLE 1.—*Noninstrumental earthquake reports, March, 1924*

Day	Approximate time, Greenwich civil	Station	Approximate latitude	Approximate longitude	Intensity Rossi-Forel	Number of shocks	Duration	Sounds	Remarks	Observer
1924	*H. m.*	CALIFORNIA	° ′	° ′			*M. s.*			
Mar. 3	23 55?	San Francisco	37 48	122 26	Slight.					Press report.
		San Jose	37 15	121 53	Slight.					Do.
9	23 20	Spreckels	36 38	121 36	4–5	1			Felt by many	Spreckels Sugar Co.
	.. 42	Salinas	36 41	121 39	3	1	3 *ca.*	None	do	E. D. Eddy.
		ILLINOIS								
2	11 18	Cairo	37 00	89 05	4	1	30	Rumbling	Felt by many	W. E. Barron.
	.. 20	Anna	37 30	89 15	4	1	25–30	Faint	Felt by several	E. V. Hale.
		KENTUCKY								
2	11 00	Lynnville	36 30	88 32					Felt by several	N. R. Tibles.
	11 15	Cadiz	36 50	87 45	4	1	30–60	None	do	J. C. Thompson.
		Calhoun	37 30	87 15		2			Felt by few	W. A. Taylor.
		Clinton	36 45	89 00	5	1	120 *ca.*	Rumbling	Felt by many	D. Johnson, P. M.
		Paducah	37 05	88 40	4?	1	20–30	do	do	F. L. Brown.
		Smithland	37 10	88 30	Faint.		60?			T. F. Bunton.
	.. 17	Blandville	37 00	89 00			5 *ca.*		Felt by many	E. W. Horr.
	.. 18	Arlington	36 50	89 00	4?				do	L. B. Owen, P. M.
		Bardwell	36 52	89 01	4	1	15		do	G. T. Jorner.
		Wickliffe	37 00	89 05	5	2–3		Faint	do	J. A. Miller.
	.. 20	La Center	37 05	89 00	4–5	2	30	Rumbling		Bettie Clements.
		Mayfield	36 45	88 40	5	1		do	Felt by many	N. E. Danthit.
		Marion	37 20	88 05		1	15		Felt by several	B. C. Paris.
		Murray	36 40	88 15	Heavy.	1	Long.	Rumbling		S. F. Holcomb.
	.. 27	Benton	36 55	88 25	5	1		Rattling	Felt by many	W. L. Pierce.
	.. 30	Hickman	36 34	89 12	4	1	30	Rumbling	do	H. A. Rice.
		Hopkinsville	36 50	87 30	4?	1	Brief.		do	W. E. Graves.
		MISSOURI								
2	11 30	New Madrid	36 35	89 32		1	1 *ca.*	Rumbling	Felt by several	Jessie G. Smith.
		TENNESSEE								
2	11 20	Nashville	36 10	86 45	2	1	1–2	Faint	do	Mrs. C. H. Harbrough.
	.. 23	Clarksville	36 30	87 25	2	-4	3–4	None	do	L. W. Hodgson.
	.. 30	Savannah	35 15	88 15	4?	2		do	Felt by many	F. H. Stendau.

TABLE 2.—*Instrumental seismological reports, March, 1924*

[Time used: Mean Greenwich, midnight to midnight. Nomenclature: International. For description of stations and instruments see REVIEW for January, 1924]

Date	Character	Phase	Time	Period T	Amplitude A_E	Amplitude A_N	Distance	Remarks
ALASKA. *U. S. C. and G. S. Magnetic Observatory, Sitka*								
1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		e_E	10 34 06					Weak phases obscured by wind tremors.
		L_E1	10 38 03	37				
		L_E2	10 46 02	20				
		L_N	10 37 41	36				
		M_E	10 54 39	15	*600			
		M_N	10 56 22	19		*600		
		F_E	11 36 ..					
		F_N	11 31 ..					
4		e_E	12 10 05					Very slight.
		e_N	12 09 42					
		F	12 32 ..					
15		O	10 30 48				5,600	Wind tremors severe.
		P	10 39 55					
		S_E	10 47 08	15				
		e_N	10 49 33					
		SR_E	10 50 49	12				
		L_E1	10 55 12	13				
		L_E2	10 56 58	28				
		L_N	10 57 24	21				
		M_E	10 59 36	16	*300			
		M_N	10 59 37	21		*500		
		C_E	11 05 ..					
		F	11 42 ..					
		S(?)	0 11 57	6				
30		L_E	0 12 36	13				
		L_N	0 12 51	13				
		M_E	0 13 17	12	*4,900			
		M_N	0 13 36	11		*3,100		
		F_E	0 48 ..					
		F_N	0 40 ..					
ARIZONA. *U. S. C. and G. S. Magnetic Observatory, Tucson*								
1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		O	10 07 36				3,660	N component not operating during March.
		P_E	10 14 29	5				
		ePR_E	10 15 46	5				
		S_E	10 19 56					
		e_E	10 20 21	18				
		SR_E	10 22 14					
		$L1_E$	10 24 31	16				
		$L2_E$	10 28 15					
		M_E	10 29 07	20	*2,000			
		F_E	11 15 ..					
4		eP_E	11 51 06					Interpretation based on report of Porto Rico observatory.
		S_E	11 55 59					
		L_E	11 01 13	11				
		M_E	11 05 01	17	*100			
		F_E	11 30 ..					
11		e_E	10 58 25	12				
		M_E	11 02 05	19	*100			
		F_E	11 13 ..					
30		P_E	0 14 02	4				
		S_E	0 18 41					
		L_E	0 22 58					
		M_E	0 23 58	10	*200			
		F_E	0 42 ..					
CALIFORNIA. *Theosophical University, Point Loma*								
1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 15			15 00 00		50	50		Tremors during preceding 24 hours.
COLORADO. *Regis College, Denver*								
1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		L_N	10 24 ..	30–35		*1,000		Costa Rica. Preliminaries absent on NS and doubtful on EW.
		L_E	10 29 ..	20–25	*500			
		M_N	10 28 ..			*1,000		
		M_E	10 31 ..		*500			
		F_N	10 42 ..					
		F_E	10 39 ..					
5								Wavelets at interval during day probably seismic
15								Frequent wavelets; probably seismic.
30		L	0 15 ..	6–8	*2,000			
		M	0 17 ..	6–8		*1,500		
		F	0 24 ..					
DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.*								
1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		P	10 13 52				3,300	Costa Rica.
		S	10 18 56					
		L	10 22 04	22				
		F	11 40 *ca.*					
4		P	11 49 56				3,200	
		S	11 54 50					
		L	11 58 06	22				
		F	14 *ca* ..					
5		e	12 19 ..					
		F	12 32 ..					
11		e	10 53 ..					
		L	10 57 ..	20				
		F	11 20 *ca.*					
15		P	10 54 25					
		L	11 15 ..	24				
		L	11 19 ..	20				
		F	11 45 ..					
16		e	1 34 ..					
		F	1 45 ..					
24		P?	20 35 26					
		S	20 40 27					
		L	20 45 30	16				
		F	21 10 *ca.*					
25		P	14 13 08					
		PR1	14 14 10					
		S	14 18 22					
		L	14 23 ..	20				
		F	14 45 ..					
25		P	15 09 34					
		PR1	15 10 32					
		S	15 15 10					
		L	15 19 15	20				
		F	15 40 ..					
26		eL	20 58 ..	20				
		F	21 05 ..					
30		e	0 24 ..					No phases.
		L	0 29 ..	20				
		F	1 10 ..					
HAWAII. *U. S. C. and G. S. Magnetic Observatory, Honolulu.*								
1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		e_E	10 19 40					
		e_N	10 28 06					
		S_E	10 28 30	16				
		S_N	10 29 04	15				
		e_N	10 31 52					
		eSR_N	10 37 21	30				
		eSR_E	10 38 08					
		e_N	10 40 00	12				
		iL_E	10 40 34					
		M_E	10 41 45	20		85		
		M_N1	10 38 14	30	195			
		M_N2	10 49 40	8	20			
		F_E	12 22 ..					
		F_N	12 30 ..					
11		e_E	11 14 00					
		e_N	11 12 30					
		F	11 31 ..					
14		e_N	2 50 ..					Record on E obscured by overlapping traces.
		F_N	2 56 ..					
15		O	10 31 04				6,300	
		P_E	10 40 52					
		iS_E	10 48 44	24		40		
		e_N	10 48 42					
		S_N	10 49 00	22	45			
		e_E	10 53 28					
		e_N	10 54 00	9				
		iL	10 54 40	21				
		M_E	10 57 14	25	75			
		M_N	10 56 58	25		75		
		F_E	12 00 ..					
		F_N	11 40 ..					
26		eL	20 20 41					
		M_E	20 23 22	12	18			
		M_N	20 23 45	19		45		
		F	20 46 ..					
30		L	0 24 09					
		M_E	0 27 29	17	110			
		M_N	0 28 07	8		60		
		F_E	1 33 ..					
		F_N	1 30 ..					

* Trace amplitude.

ILLINOIS. *U. S. Weather Bureau, Chicago*

1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		eL	2 27 ..					Small; may not be seismic.
		F	2 35 ..					
4		P	10 14 24				3,300	Costa Rica.
		S	10 19 30					
		L?	10 22 12					
		Me	10 27 30		*23,000			Large, irregular disturbances.
		F						In next quake.
4		P	11 50 22				3,300	
		S	11 55 28					
		L?	11 58 10					
		M_E	12 04 *ca.*		*4,500			
		F	15 *ca.* ..					
5		e	12 20 50					
		F	12 40 ..					
6		e	9 36 ..					
		F	9 50 ..					
11		e	10 47 ..					
		S?	10 52 20					
		F	12 20 *ca.*					
11		e	20 48 ..					
		F	21 25 ..					
11		e	23 02 ..					
		F	23 30 *ca.*					
12		e	3 00 ..					
		F	3 30 *ca.*					
12		e	14 15 ..					
14		e	2 47 ..					
		L	3 02 20	20				
		F	3 30 *ca.*					
15		P	10 53 08				5,800	
		S	11 01 33					
		L	11 08 15	35				
		L	11 11 ..	26				
		F	13 *ca.* ..					
16		e	1 33 ..					
		F	2 *ca.* ..					
20		e	10 10 30					
		F	10 40 *ca.*					
22		e	13 07 ..					
		F						Lost in changing sheets.
24		e	11 53 ..					
		F	12 20 ..					
24		eP	20 36 00					
		S?	20 41 35					
		F	22 *ca.* ..					
25		P	14 13 37				3,600	
		S	14 19 02					
		F						In next quake.
25		P	15 09 54					
		PR1	15 11 00					
		S	15 21 00					No L.
		F	16 40 *ca.*					
26		P	20 29 35				3,500	
		S	20 34 50					
		eL	20 50 ..					
		F	22 *ca.* ..					
27		e	8 42 20					
		F	9 20 ..					
28		e	5 11 ..					
		F	5 30 ..					
30		P?	0 11 58				4,600	
		S?	0 18 18					
		F	2					Micros.

MARYLAND. *U. S. C. and G. S. Magnetic Observatory, Cheltenham*

1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		O	10 07 48				3,200	Tremors continue to next earthquake.
		eP_E	10 14 15					
		iP_N	10 14 03	3				
		S_N	10 18 49	21				
		e_E	10 20 35	24				
		iL_E	10 21 50	28				
		L_N	10 21 56	35				
		M_E	10 24 40	12	*5,500			
		M_N	10 26 08	12		*2,000		
		C_E	10 26 23					
		C_N	10 35 ..					

* Trace amplitude.

MARYLAND. *U. S. C. and G. S. Magnetic Observatory, Cheltenham*—Continued

1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 4		e_E	11 51 50					Interpretation. based on report of Porto Rico observatory. First two phases very weak.
		S_E	11 55 18					
		SR_E	11 57 00					
		L_E	11 59 05	15				
		L_N	12 01 05	15				
		M_E	12 01 03	12	*700			
		F	12 15 ..					
11		e_E	10 55 18					
		L_E	10 57 46	17				
		L_N	10 57 33	12				
		M_E	10 58 47	12	*200			
		M_N	11 01 08	12		*100		
		F_E	11 15 ..					
		F_N	11 10 ..					
30		e_E	0 29 29	16	*100			
		e_N	0 29 37	20				
		M_N	0 30 16	13		*500		
		F	0 38 ..					

CANAL ZONE.—*Panama Canal, Balboa Heights*

1924			*H. m. s.*	*Sec.*	μ	μ	*Miles.*	
Mar. 4		P_E	2 07 32				230*ca.*	Northwest.
		P_N	2 07 34					
		S_E	2 08 12					
		S_N	2 08 10					
		L_E	2 08 14					
		L_N	2 08 22					
		M_E	2 08 16		*1,500			
		M_N	2 08 26			*1,400		
		F_E	2 12 52					
		F_N	2 16 00					
4		P_E	10 08 40				300*ca.*	Do.
		P_N	10 08 50					
		S_E	10 09 44					
		S_N	10 09 42					
		L_E	10 10 24					
		L_N	10 09 54					Pen thrown off on NS.
		M_E	10 13 00		*82,000			
		F_E	10 43 15					
4		P_E	10 51 28				320*ca.*	Northwest. Record lost on NS
		S_E	10 52 24					
		L_E	10 52 32					
		M_E	10 53 24		*3,500			
		F_E	11 09 00					
4		P_E	11 44 52				340*ca.*	Northwest. Record lost on NS
		S_E	11 45 52					
		L_E	11 46 12					
		M_E	11 47 02		*12,000			
		F_E	12 13 00					
4		P_E	12 46 32				320*ca.*	Northwest. Record lost on NS.
		S_E	12 47 28					
		L_E	12 48 00					
		M_E	12 48 08		*1,000			
		F_E	12 55 00					
4		P_E	13 38 30				340*ca.*	Northwest. Record lost on NS. Very slight tremors 17:18 to 17:22 also.
		S_E	13 39 30					
		L_E	13 40 06					
		M_E	13 40 10		*600			
		F_E	13 46 00					
5								Slight tremors 12:09 to 12:21, and on NS. 12:24 to 12:29.
5		P_N	12 48 38				340*ca.*	Northwest.
		S_N	12 49 38					
		L_N	12 50 06					
		M_E	12 50 56		*1,000			
		M_N	12 50 34			*1,000		
		F_E	12 59 00					
		F_N	12 56 58					
5								Very slight tremors 17:45:15 to 17:49:15.
6								Very faint tremors 12:21:15 to 12:26:15.
7								Very faint tremors 18:18:16 to 18:22, and 16:40:12 to 16:47.
7		P_N	18 10 38				280*ca.*	Northwest. Faint on EW.
		S_N	18 11 26					
		L_N	18 11 32					
		M_N	18 12 24			*500		
		F_N	18 19 24					
8								Very faint tremors 7:40:12 to 7:44 and at 23:48.

* Trace amplitude.

CANAL ZONE.—*Panama Canal, Balboa Heights*—Continued

			H. m. s.	Sec.	μ	μ	Miles.	
1924 Mar. 10								Very faint tremors 18:03:44 to 18:08:32 and at 21:00:15 and 22:51:40.
11								Slight tremors at 2:59:20, 9:24, 12:05:24, 12:32:10, 12:43:30, 12:59:50, 19:39:02, 21:24, 21:37:22, 22:47:20.
11		P_E	10 41 20				425ca.	Northwest.
		P_N	10 41 20					
		S_E	10 42 36					
		S_N	10 42 32					
		L_E	10 43 24					
		L_N	10 43 19					
		M_E	10 45 44		*23,000			
		M_N	10 44 08			*49,000		
		F_E	11 06 ..					
11		P_E	16 25 00				425ca	Do.
		P_N	16 25 00					
		S_E	16 25 15					
		S_N	16 26 12					
		L_N	16 26 48					
		M_E	16 25 35		*500			
		M_N	16 26 53			*500		
		F_E	16 33 00					
		F_N	16 34 00					
11		P_E	19 43 54				410ca	Do.
		P_N	19 44 02					
		S_E	19 45 08					
		S_N	19 45 10					
		L_E	19 45 34					
		L_N	19 45 57					
		M_E	19 45 40		*400			
		M_N	19 46 00			*500		
		F_E	19 50 00					
		F_N	19 50 30					
11		P_E	20 35 24				440ca	Do.
		P_N	20 35 00					
		S_E	20 36 40					
		S_N	20 36 18					
		L_E	20 37 24					
		L_N	20 36 58					
		M_E	20 38 16		*2,000			
		M_N	20 50 20			*4,500		
		F_E	20 49 00					
		F_N	20 50 00					
12								Very slight tremors at 0:02:14, 5:16:35, 5:55:45, 19:47:12.
12		P_E	2 51 22				460ca	Northwest.
		P_N	2 51 22					
		S_E	2 52 42					
		S_N	2 52 38					
		L_E	2 53 24					
		L_N	2 53 26					
		M_E	2 54 30		*1,000			
		M_N	2 54 14			*6,000		
		F_E	3 03 00					
		F_N	3 05 00					
13								Very slight tremors at 23:48.
17								Very slight tremors at 18:01:54.
18								Slight tremor at 12:34:44.
20		P_E	9 57 34				450ca	Northwest
		P_N	9 57 31					
		S_E	9 58 52					
		S_N	9 58 49					
		L_E	9 59 37					
		L_N	9 59 30					
		M_E	9 59 56		*2,000			
		M_N	9 59 43			*3,000		
		F_E	10 08 15					
		F_N	10 09 00					
20								Slight tremors at 19:54:32, 22:37.
21								Slight tremors at 8:58:28, 11:27:18.
24		P_E	11 41 38				380ca	Northwest.
		P_N	11 41 23					
		S_E	11 42 44					
		S_N	11 42 29					
		L_E	11 42 51					
		L_N	11 42 35					
		M_E	11 42 57		*1,400			
		M_N	11 42 55			*1,200		
		F_E	11 46 00					
		F_N	11 50 23					

* Trace amplitude.

CANAL ZONE.—*Panama Canal, Balboa Heights*—Continued

			H. m. s.	Sec.	μ	μ	Miles.	
1924 Mar. 24								Slight tremors 7:51:48 to 7:55:20, and at 22:51.
24		P_E	20 30 32				450ca	Northwest.
		P_N	20 30 30					
		S_E	20 31 16					
		S_N	20 31 18					
		L_E	20 32 04					
		L_N	20 31 52					
		M_E	20 33 10		*12,000			
		M_N	20 33 20			*26,000		
		F_E	20 52 06					
		F_N	20 53 00					
25								Slight tremors at 8:47:20, 16:13:24, 16:50:06.
25		P_E	15 04 48				300ca	Northwest.
		P_N	15 04 36					
		S_E	15 05 52					
		S_N	15 05 24					
		L_E	15 06 20					
		L_N	15 05 50					
		M_E	15 07 10		*9,800			
		M_N	15 07 14			*14,000		
		F_E	15 10 10					
		F_N	15 25 14					
26								Slight tremors at 1:02, 5:49.
27		P_E	8 30 46					
		P_N	8 30 58					
		S_E	8 31 42					
		S_N	8 31 44					
		L_E	8 32 10					
		L_N	8 32 14					
		M_E	8 32 34		*2,000			
		M_N	8 32 42			*3,400		
		F_E	8 42 00					
		F_N	8 46 38					
28								Very slight tremors at 23:15, 15:00, 16:32:08, 16:34, 20:42.
28		P_E	4 58 02				450ca.	Northwest.
		P_N	4 58 02					
		S_E	4 59 08					
		S_N	4 59 06					
		L_E	4 59 20					
		L_N	4 59 28					
		M_E	4 59 32		*1,000			
		M_N	4 59 48			*1,400		
		F_E	5 04 00					
		F_N	5 08 00					
29		P_E	20 25 22				90ca.	Direction unknown.
		P_N	20 25 23					
		L_E	20 25 36					
		L_N	20 25 38					
		M_E	20 25 39		*2,800			
		M_N	20 25 41			*1,200		
		F_E	20 27 53					
		F_N	20 28 58					

VERMONT.—*U. S. Weather Bureau, Northfield*

			H. m. s.	Sec.	μ	μ	Km.
1924 Mar. 4		P	10 14 40				
		S?	10 19 28				
		L	10 23 40				
		L	10 26 40	20			
		M_E	10 30 ..		*22,000		
		F	11 25 ca				
4		P	11 50 40				
		S	11 55 40				
		L	11 59? ..				
		L	12 02 ..	24			
		F	12 30 ca				
11		e	10 58 ..				
		F	11 15 ca				
15		eL	11 09 ..				
		L	11 16 ..	20			
		L	11 20 ..	16			
		F	11 35 ca				
30		e	0 28 ..				
		F	0 50 ..				

* Trace amplitude.

PORTO RICO. *U. S. C. and G. S. Magnetic Observatory, Vieques*

1924			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 4		O	10 07 53				2,220	Tremors on E continue to next earthquake.
		iP	10 12 30					
		iS$_E$	10 16 12					
		iS$_N$	10 16 18					
		iS$_E$	10 16 40					
		iL$_E$	10 17 30	20				
		L$_N$	10 17 47	20				
		M$_E$	10 20 38	18	*8,000			
		M$_N$1	10 16 47			*3,600		
		M$_N$2	10 23 38	15		*2,400		
		C$_E$	10 26 ..					
		F$_E$	10 42 ..	12				
4		O	11 43 51				2,230	No definite maximum on N.
		P	11 48 29	6				
		S	11 52 12	12				
		e$_E$	11 53 24	22				
		eL$_E$	11 55 18	18				
		eL$_N$	11 54 40	17		*100		
		M$_E$	11 56 18	15	*200			
		F$_E$	12 10 ..					
		F$_N$	12 09 ..					
11		O	10 41 01				2,320	No definite maximum during L on N component.
		P$_E$	10 45 49	6				
		P$_N$	10 45 57	6				
		S$_E$	10 49 39	8				
		S$_N$	10 49 52					
		L$_E$	10 52 34	17				
		L$_N$	10 51 51					
		M$_E$	10 55 06	16	*500			
		M$_N$	10 50 00	9		*300		
		F$_E$	11 14 ..					
		F$_N$	11 06 ..					
24		O	20 29 07				2,300	No definite L phase.
		P$_E$	20 33 58	7				
		P$_N$	20 33 53	4				
		S$_E$	20 37 42	10				
		S$_N$	20 37 49					
		M$_E$	20 38 03	8	*300			
		M$_N$	20 38 00	8		200		
		F$_E$	20 59 ..					
		F$_N$	20 46 ..					
25		O	14 06 43				2,300	Do.
		P$_E$	14 11 29	6				
		P$_N$	14 11 37	4				
		S$_E$	14 15 18	10				
		S$_N$	14 15 28	7				
		L$_E$	14 19 02	15	*200			
		L$_N$	14 22 38	13				
		M$_N$	14 22 52	13		*200		
		F$_E$	14 34 ..					
		F$_N$	14 28 ..					

CANADA. *Dominion Observatory, Ottawa*

1924			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 4		eL17	2 26 ..	22	2			
		L17	2 29 ..	14				Small.
		F	2 35 ..					
4		O	10 07 40				3,900	San Jose, Costa Rica.
		P	10 14 51					
		PR1$_N$	10 16 24					
		iS$_E$	10 20 32					
		eL?	10 24 ..					
		M$_E$	10 29 ..	15	488			
		L$_E$	10 37 ..	15	106			
		L$_E$	11 10 30	14	26			
		F						Merged in next quake.
			HALIFAX RECORD					
		O	10 07 31				4,380	Much better marked on NS than on EW.
		P	10 15 17					
		PR1$_N$	10 16 48					
		S	10 21 26					
		eL	10 26 48					
4		O	11 43 54				3,780	
		PI	11 50 56					
		iI	11 52 15					
		iI	11 52 46					
		S	11 56 30					
		eL	12 00 ..					
		M17	12 03 30	16	131			
		MI	12 03 30	16		58		
		L17	12 13 ..	15	11			
		eL17	13 02 ..	30				May be another quake.
		eL17	13 59 ..	22				
		eLR1	14 14 *ca*					
		F						Lost changing sheets.
4		e17	17 30 24					
		eL17	17 32 ..					
		L17	17 34 to					
			17 40 ..	12	•			Small.
		F						Micros.
5		PR1?	4 47 19					
		S?	4 53 23					
		SR1?	4 58 37					
		eL	5 05 ..					
		L	5 22 ..	26	9			
		F	6 26 ..					

*Trace amplitude.

CANADA. *Dominion Observatory, Ottawa*—Continued

1924			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 5		eL17	12 23 ..					
		M17	12 27 ..	15	5			
		L17	13 06 ..	15	3			
		F	13 25 ..					
6		i17	9 39 04					
		F	9 54 ..					
6		eL17	12 38 ..					Small.
		F	12 53 *ca.*					
7		eL17	8 11 30					
		L17	8 20 ..	15				Do.
		F	8 45 *ca.*					
7		e17	18 21 42					
		eL17	18 26 ..	24				Do.
		M17	18 29 ..	15	4			
10		i17	(18 16 30)					
		eL17	(18 21) ..	18				Do.
		F	(18 35) ..					
11		O	(10 39 27)				(4,630)	
		eP?	(10 47 30)					
		ePR1?	(10 53 52)					
		S	(10 53 52)					
		SR1?	(10 56 34)					
		SR2?	(10 57 22)					
		eL	(10 59 00)					
		M	(11 01 23)	15	68			
		L	(11 40) ..	12	3			
		F	(13 25) ..					
11		eL17	(17 42) ..					
		L17	(18 25) ..					
		L17	(18 30) ..	30	6			
		F	(19 00) ..					
11		eL17	(20 07) ..					
		M17	(20 57) ..	30	18			
		F	(21 35) ..					
11		eL17	(22 11) ..	15	4			
		F	(22 35) ..					
12		eL17	(3 14) ..					
		M17	(3 16) ..	15	9			
		F	(3 30) ..					
12		eL17	14 16 ..					
		F						Micros.
13		e17	11 04 19					
		eL17	11 11 ..					
		L17	11 28 ..					Small.
		F						Micros.
14		e?17	2 43 34					
		e17	2 51 45					
		eL17	2 56 ..					
		L17	3 03 ..	15	4			
		F	3 30 *ca.*					
15		O	10 45 16				4,800	
		iP	10 53 31					
		eS	11 00 02					
		SR2	11 04 11					
		eL	11 07 45					
		M	11 19 ..	16	40			
		L	11 30 ..	15	4			
		L	11 58 ..	15	4			
		F	13 10 *ca.*					
16		e?17	1 31 44					
		S?17	1 37 33					
		SR?17	1 38 53					
		eL17	1 40 45					
		L17	1 44 ..	20	6			
		F	2 05 ..					
16		eL17	10 46 ..					Small.
		F	11 00 *ca.*					
20		eL17	10 12 ..					
		L17	10 17 ..	17	9			
		L17	10 21 ..	13	3			
		F	10 35 ..					
22		eL17	13 07 ..	20	6			
		L17	13 21 30	30	18			
		M	13 24 ..	16	18			
		F	13 45 ..					
24		e17	11 57 42					
		eL17	12 00 ..	15	4			
		F	12 20 *ca.*					
24		eL17	20 09 30					Do.
		F	20 19 ..					
24		O	20 28 16				4,300	
		eP	20 35 56					
		PR1	20 37 28					
		S	20 42 00					
		SR1	20 44 20					
		SR2	20 45 08					
		eL	20 47 ..					
		M	20 49 28	15	29			
		L	21 00 ..	15	6			
		L	21 14 ..	12	3			
		F	22 15 *ca*					

CANADA. *Dominion Observatory, Ottawa*—Continued

1924			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 25		eL17	12 36 --					
		L17	12 41 --	15				Small.
		L17	12 50 30	15				Do.
		F	13 05 --					
25		O	14 06 49				3,900	
		eP	14 14 00					
		PR2	14 15 20					
		eS	14 19 41					
		SR1	14 21 52					
		SR2	14 22 24					
		eL	14 24 20					
		M1	14 27 --	15	29			
		M2	14 32 30	15	18			
		L	14 38 --	12	4			
		L	14 57 --	12	4			
		F						Lost in next quake.
25		O	15 03 00				4,360	
		iP	15 10 23					
		PR1	15 11 30					
		eS	15 16 14					
		SR1	15 18 15					
		SR2	15 19 00					
		eL17	15 21 00					
		M	15 23 45	15	23			
		L	15 36 --	15	3			
		L	16 00 --	15	3			
		F	16 40 *ca*					
26		eL17	1 18 --	16				Small.
		F	1 29 --					
26		eL17	15 41 30	16				Do.
		F	16 00 --					
26		O	20 23 28				4,450	
		eP	20 31 18					
		e	20 32 18					
		eS	20 37 30					
		SR?	20 40 30					
		eL	20 42 --					
		M1	20 56 --	28	16			
		M2	21 01 30	20	9			
		L	21 08 --	18	5			
		L	21 14 --	16	4			
		F	22 30 *ca*					
27		e17	8 45 --					
		L17	8 50 --	18	6			
		L17	8 55 --	10				Do.
		F	9 15 *ca*					
28		e?17	5 11 --					
		L17	5 15 --	15	4			
		F	5 30 --					
30		O	(0 12 30)				(2,510)	
		eP?	(0 17 38)					
		eS	0 21 44					
		eL	0 23 26					
		M	0 28 30	12	58			
		L	0 31 30	12	23			
		L	0 55 --	12				Do.
		F	2 00 *ca*					
30		eL17	12 28 --					Do.
		F	12 43 --					

CANADA. *Meteorological Service of Canada, Toronto*

1924			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 2		L	10 01 15					Slow waves may not be seismic.
		L	10 34 32					
W		L	10 50 23					
		F	11 06 00					
		L	10 44 23					
N		L	10 50 15					
		F	11 18 --					
4		e	2 24 08					N-S component barely affected.
W		L	2 25 38	22				Small amplitude.
		F	2 36 --					
4		O	10 07 24					
		P	(10 14 20)					P very small and indistinctly marked.
			(10 14 30)					
		eS	10 19 50	8–10				
		iS	10 20 00					S pronounced and came in at first as a slow easterly movement.
		SR	10 21 45	20				
		iL	10 22 33	18		300		
W		L	10 24 15	25				
		M	10 25 30	15		667	3,710	
		L	11 08 05	19				Large vibrations.
		L	11 10 15	11		41		
		F	-- -- --					Merged into next quake.
		O	10 07 36					
		eP	10 14 30				3,660	
		iP	10 14 32	8				
		iS	10 19 56					
		iS	10 20 02					Costa Rica.
		iL	10 22 36	17	82			Disastrous.
		iL	10 25 37	23	218			
N		M	10 27 44	20	365			
		L	11 03 00	17				
		L	11 08 52	13				
		F	-- -- --					Merged into next quake.

CANADA. *Meteorological Service of Canada, Toronto*—Continued

1924			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 4		P	-- -- --					Masked by trialers.
		eS	11 55 54					
		iS	11 55 56					
		eL	11 58 17					
		iL	11 58 34	12				
		L	12 00 46					
			12 04 38	15				
W		M	12 03 15	15		179		
		F	-- -- --					Merged into next quake.
4		?eS	11 55 52					Vibrations from last quake interfere with P and S.
		L	11 58 27					
		iL	12 02 00	15				
N		M	12 03 10	15	61			
		F	-- -- --					Merged into next quake.
4		e	12 59 52					
		e	13 00 22					After shock reported from Costa Rica.
		L	13 02 30					
			13 06 43	12		13		
W		F	-- -- --					Merged into next quake.
		L	13 00 37					Small amplitude.
N		L	13 04 15					
		F	-- -- --					Merged into next quake.
4		L	13 58 23					Sinusoidal.
			14 00 45	15		6		
		L	14 13 08	15		6		
			14 16 00					
W		F	-- -- --					Micros.
		L	14 00 23					Irregular waves, small amplitude.
N		F	-- -- --					Lost, off paper at 14h. 16m.
4		e	17 29 45					
		eL	17 32 30					
		L	17 33 23	15				
			17 35 36			5		
W		F	-- -- --					Micros.
		e	17 34 30					
		L	17 36 10					
			17 37 15	15	2			
N		F	-- -- --					Micros.
5		e?	4 46 11					Continuous small uniform waves preceded by micros before 4 h. 46 m.
		e	4 46 38	8				
		eS	4 53 17	10				
		SR	4 58 45					
		eL	5 04 15					
W		L	5 05 38			3		
		L	5 06 08	12				
		F						Micros.
		eP?	4 46 38					
		iS	4 53 19				4,980	
		L	5 00 20	15				Micros before 4 h. 46 m.
		L	5 04 38					
N		L	5 06 08	8				Irregular.
		i	5 06 25	10	3			
		F						Micros.
5		e?	12 19 27					
		i	12 21 45					
		L	12 24 15	23–15				
			12 27 34					
W		F						Micros.
		e	12 18 45					
		L	12 26 23					
		L	12 26 37		3			
			12 34 30	8				
N			12 36 30					
		F	12 50 15					
5		L	13 05 38	23				Sinusoidal small waves.
		L	13 06 23					
			13 08 22	15		5		
			13 22 19					
W			13 24 --					
		F						Micros.
		S? or L	13 06 25	6				Minute waves preceding, and micros.
			13 07 30	8				
		L	13 08 20					
		e	13 14 10	8				
N		L	13 17 23					Small sinusoidal waves.
		L	13 22 08					
			13 23 52	9				
		F						Micros.
6		L	?10 28 15					Slow waves.
			?10 38 --					
W		L	10 38 30					
			10 49 45	30		10		
		F	10 58 --					
		L	10 17 00					Do.
N		L	10 18 00					
		L	10 20 30					
		L	10 34 17	23	6			
		F	10 54 --					

CANADA. *Meteorological Service of Canada, Toronto*—Continued

1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 6		e	12 38 23					N-S component barely effected.
W		F	12 54 00					Small amplitude.
7		L	8 17 30					N-S component little effected.
W		F	8 52 --					Slow waves.
7		L	18 27 15	15		6		High west wind affected boom.
		L	18 29 15					
		L	18 27 52		4			erratic.
N		i	18 37 15					
		F	18 53 --					
8		L	9 38 15					Slow uniform waves.
W			10 14 --					May not be seismic. N-S component not affected
9			9 34 23	30				N-S component little affected.
W			11 01 30					May not be seismic.
10		i	18 15 49					E-W component affected by high wind.
N		L	18 27 35					Small amplitude.
		F						Micros.
11		P						Masked by micros and wind.
		i	10 49 17					
		e	10 52 38					
W		eS	10 53 08					
		e	10 55 23	10				
		i	10 56 02	15		33		
		iL	10 58 56	19		73		
		M	11 00 43	13		106		
		F						Micros and wind.
		P?	10 47 05					P. poorly defined.
		i	10 52 23					Irregular.
N		S	10 53 08					
		L	10 56 15					
		iL	10 58 32	11				
		L	10 59 09	23				
		iL	11 00 --	11			4,280	
		M1	11 01 20	12	26			
		M2	11 04 08	15	26			
		F	13 38 --					
11		L	16 42 05					Uniform waves, small amplitude.
W			16 44 --	15				Boom affected by wind and micros.
		L	16 42 08					
N		L	16 46 15					Small amplitude.
		F?	16 54 --					
11		L	20 00 23	15				N-S component, little affected.
W		L	20 01 15	11		4		
		F						Micros.
11		e	20 48 38					
		i	20 48 58					
W		L	20 50 34	30				
		L	20 52 00	19				
		M	20 53 00	19		29		
		L	20 54 22	10				
		F						Micros.
		L	20 49 15					Sinusoidal.
M		L	20 53 33	15	5			
			20 57 30					
		i	21 01 40					
		F	21 16 --					
11		L	23 04 15					
		iL	23 06 15					
W		e	23 17 25	15		4		
		F						Micros.
	11	L	23 02 41					
		L	23 10 53	23	14			
N			23 12 15	15				
		L	23 13 45					
		F	23 24 --					
12		L	3 05 00					
W		L	3 08 00	15-12				Marked micros going on.
			3 10 45			12		Marked micros.
		F						
		eL	3 05 34					
		e	3 08 41					
N			3 09 00					
			3 14 --					
		M	3 11 34	15	6			
		F	3 28 00					

CANADA. *Meteorological Service of Canada, Toronto*—Continued

1924			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 12		e	14 18 45					Micros and heavy wind mark phases.
W		i	14 20 22					
		i	14 08 15					
		L	14 18 07					
N		L	14 19 53	15	6			
			14 21 15					
		F	14 30 --					
13		L	11 14 23					
		L?	11 17 08					
W		F						Micros, small amplitude.
		L?	11 14 53					
N		L	11 21 15					Small.
		F						Micros.
14		L	3 00 08					Wind effect interferes with early phases.
		L	3 02 10					
		L	3 08 32					
W			3 09 30	15		3		Slow waves.
		F						Micros.
		P?	2 42 53					
		S	2 51 19					
N		L	3 00 30				6,940	
		L	3 06 15					
		L	3 11 38	15	2			
		F						Micros.
15		eP	10 53 33					Marked micros precede P.
		iP	10 53 45	12				
		eS	11 00 15					
W		L	11 08 26	23				
		L	11 17 15	19			5,000	
		M	11 17 30 / -- -- 39	19		44		
		L	11 34 08	15				
		F						Micros.
		iP	10 53 30					
		i	10 53 37	9				
N		S	11 00 15					
		eL	11 08 09					
		L	11 14 00	23				
		L	11 17 45	15			5,050	
		M	11 18 00		18			
		L	11 24 53	15				
		L	11 30 05					Irregular.
		F	13 14 --					
16		eS	1 37 35					Micros mask P.
W		L	1 42 10					
		?iL	1 45 00					
		L	1 45 30	12		4		
		F						Wind effect and micros.
		iP	1 31 27					Small micros before P.
N		eS	1 37 30					
		iS	1 37 32					
		L	1 41 34				4,340	
		L	1 46 32					
		L	1 48 00	15	5			
		F						Micros.
16		L	?10 51 00					
W		F						Wind and micros.
		L	?10 51 00					
N		F						Micros.
20		L	10 12 15					
W		L	10 14 15 to 10 17 10	23-15		10		
		F	?10 38 --					
		L	10 12 10					
N		iL	10 17 34					
		L	10 19 17 to 10 20 10	15	5			
		F	10 36 00					
22		L	13 09 08	15		5		
W			13 10 00					
		F						Merged into next quake.
		eL	13 09 08	15	4			
N		L	13 10 40					
		F						do.
22		?eS	13 20 12	8-15				
		iS	13 20 15					P possibly in micros.
W		i	13 24 10					
		eL	13 24 53	26				
		L	13 26 00	15				
		M	13 26 24	15		19		
		F	?13 46 00					
		i	?13 13 27					
		i or S	13 20 10					Micros render early waves doubtful.
N		i	13 20 13					
		i	13 20 15	8				
		L	13 24 45					
		L	13 28 00					
		M	13 26 53	15				
			13 27 08		11			
		F	13 48 00					

CANADA. *Meteorological Service of Canada, Toronto*—Continued

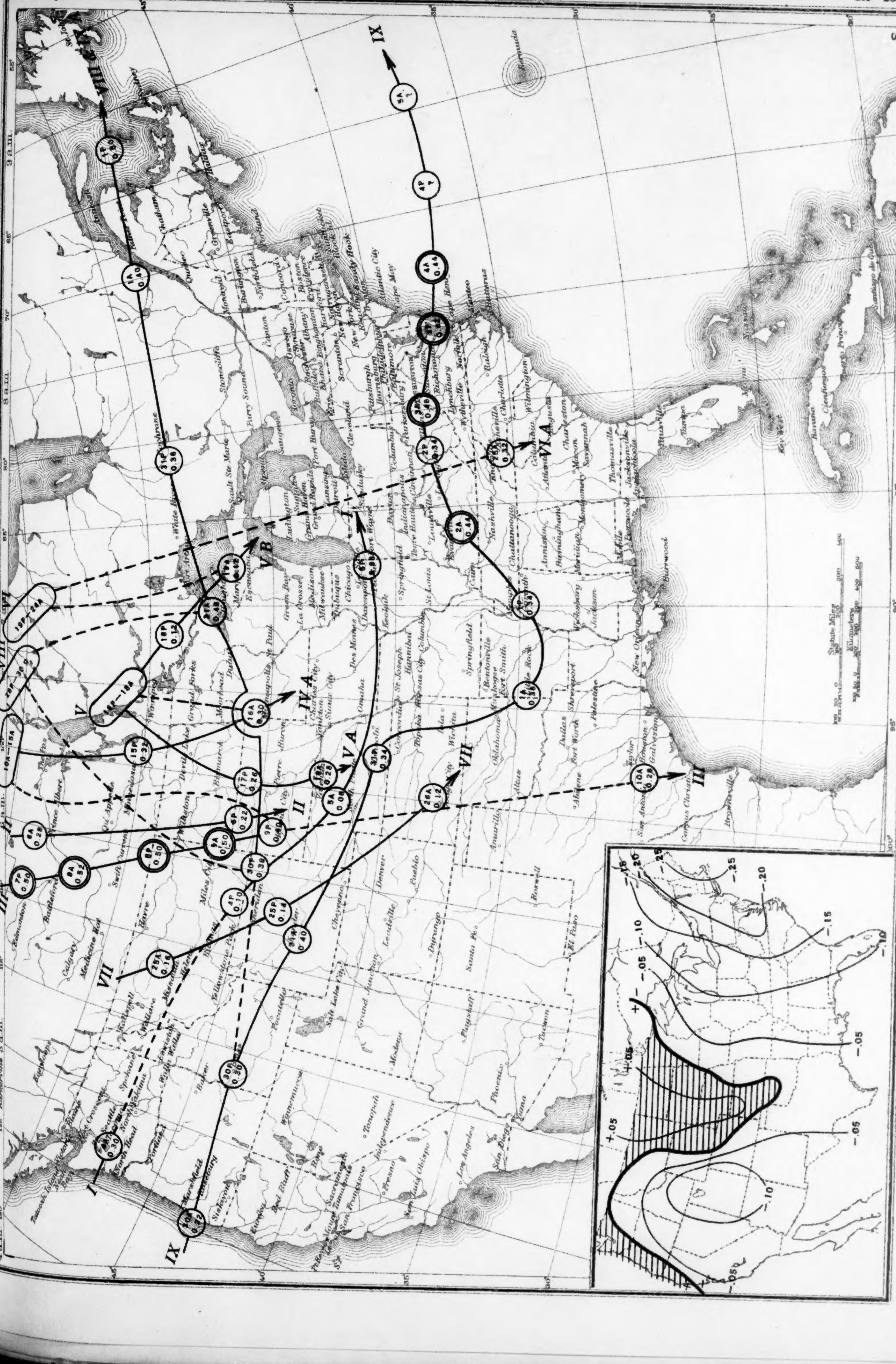
1924			H. m. s.	Sec.	μ	μ	Km.	
Mar. 24		L	11 55 30					
W		L	11 58 38	15		5		
			12 00 34					
		F	12 20 ..					
		L	11 58 45					Very small amplitude.
N		L	12 00 08					
		F	12 22 ..					
24		L	20 10 53					E-W component, wind masked phases.
N		F	20 18 00					Extremely small.
24		e	20 37 21					
		eS	{20 42 10 / .. .. 15}					
W		e	20 43 45					
		SR1	20 44 13	10				
		eL	20 47 08	25				
		L	20 47 30	15				
		M	20 48 47	15		45		
		F?	22 30 ..					
		i	20 37 15	6				
N		eS	20 42 15					S poorly defined.
		iS	20 42 20					
		SR	20 44 35					
		L	20 47 41	15				
		M	20 51 04	17	9			
		F	22 10 ..					N-S component barely effected.
25		L	12 42 22					Small amplitude.
W		F	13 02 00					
25		iPR	14 15 00					True P not recorded.
		S	14 19 45					
W		iSR	14 21 19					
		L	14 24 04					
		L	14 25 40	17				
		M	14 26 32	15		43		Paper off 15:12 m.
		F						
		iP	14 13 45					
		iPR	14 14 55					
N			.. 15 02					
		eS	14 19 45					
		L	14 25 00					
		L	14 26 08					Irregular.
		L	14 30 00	15				
		M1	14 30 11		21		4,220	
		M2	14 30 25	15				
		F						Vibrations when paper was changed at 15h. 12m.
25		L	15 38 00	15				Paper being changed during early phases.
		L	15 51 00					
W		L	16 00 23					
		F	?16 48 ..					
		L	15 43 24	15	5			Do.
N		F	16 40 ..					
26		L	1 17 33					N-S component not effected.
W		F	1 30 ..					Small amplitude.
26		eP	(20 30 50)					
		P	(20 31 00)					
		e	20 36 45					
		eS	20 37 08					P. and S. poorly defined.
		L	20 43 45					

CANADA. *Meteorological Service of Canada, Toronto*—Continued

1924			H. m. s.	Sec.	μ	μ	Km.	
Mar. 26		L	20 50 37					
W		L	20 58 15	23-15		13		
			21 19 30					
		F	22 30 ..					
		e	?20 36 53					
N		L	20 54 08					
		L	20 58 00	23				
		L	21 00 53	20	6			
		F	21 48 ..					
27		iP	?8 38 32					Small micros make P doubtful.
		i	8 45 00					
		e	(8 45 25)					
W		i	(8 45 43)	10				
		L	8 47 15					
		L	8 48 43	15		6		
			8 52 45					
		F	9 14 00					
		e	8 45 30					
N		L	8 49 15	15				
		L	8 52 03	19	9			
		F	9 16 ..					
28		L	5 12 00					
W		L	5 15 37					
			5 19 00	15		6		Micros.
		F						Do.
		L	5 17 45	15	4			Marked micros.
N		F	?5 30 00					
30		P						Masked by wind effect.
		eS	(0 21 20)					
			(. .. 23)					
W		iL	0 24 24					
		L	0 26 38					
		M1	0 27 35					
		M2	0 27 51	16		66		Wind effecting boom
		F						
		P						Masked by micros.
		eS	0 21 21					Well defined.
N		iS	0 21 26					L waves.
		eL	0 24 30					
		iL	0 27 17					
		M1	0 27 38					
		M2	0 27 53	15	88			
		M3	0 29 12	8	44			
		iL	0 35 09	10				
		i	0 39 23	8				
		F	2 00 00					
30		e	12 28 50					
W		L	12 30 50					
			12 31 52	12		2		
		F						Micros.
		L	12 28 38	15-12				
N			12 29 52		3			
		F						Micros.

Reports for March, 1924, have not yet been received from the following stations:

MASSACHUSETTS. *Harvard University.* Cambridge.
MISSOURI. *St. Louis University.* St. Louis.
DISTRICT OF COLUMBIA. *Georgetown University.* Washington.
NEW YORK. *Cornell University*, Ithaca; *Fordham University*, New York.
CANADA. *Meteorological Service of Canada*, Victoria.



(Plotted by Wilfred P. Day.)

Chart II. Tracks of Centers of Cyclones, March, 1924. (Inset) Change in Mean Pressure from Preceding Month.

(Plotted by Wilfred P. Day.)

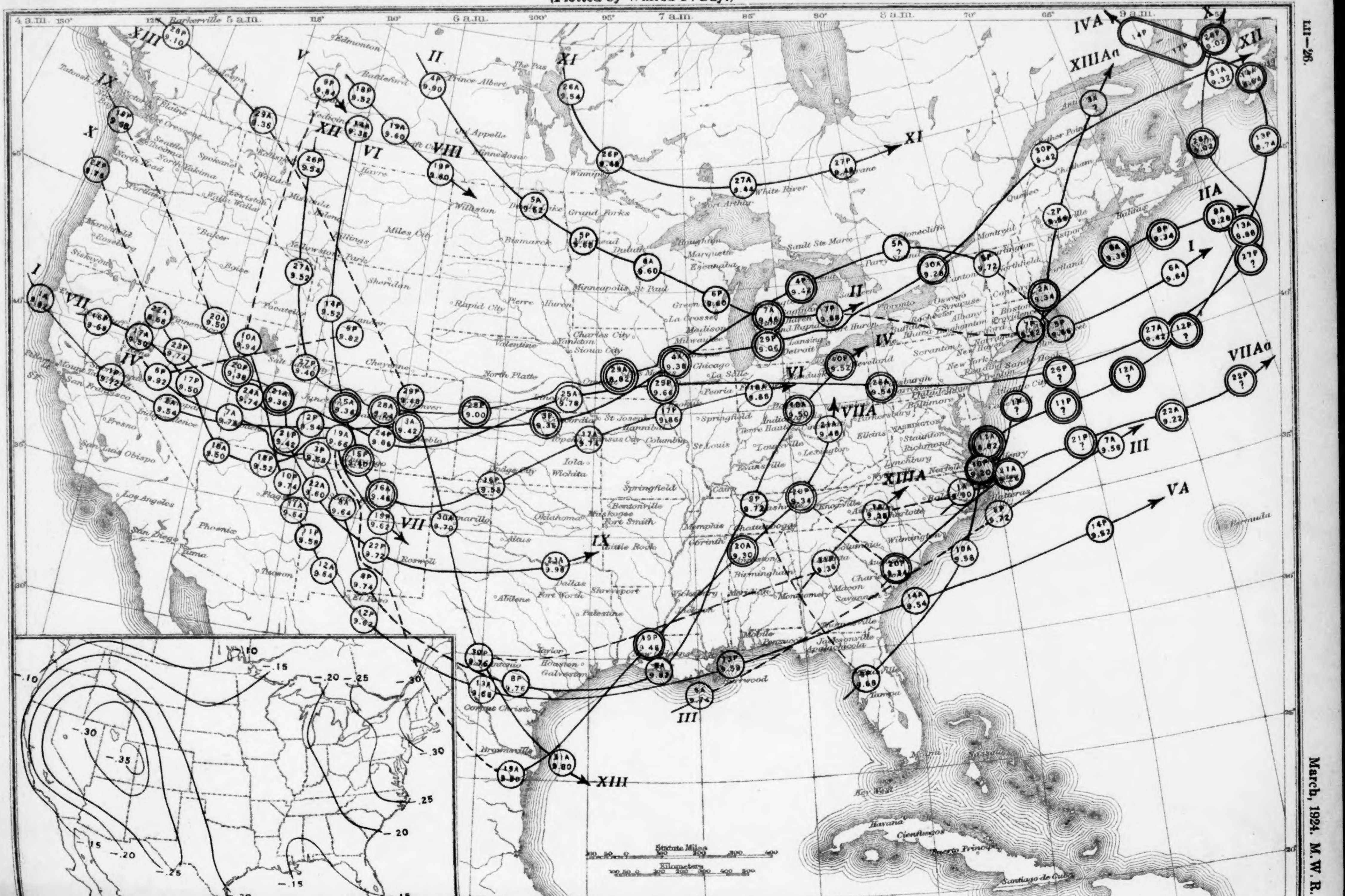


Chart III. Departure (°F.) of the Mean Temperature from the Normal, March, 1924.

Chart IV. Total Precipitation, Inches, March, 1924. (Inset) Departure of Precipitation from Normal.

Chart V. Percentage of Clear Sky between Sunrise and Sunset, March, 1924.

Chart V. Percentage of Clear Sky between Sunrise and Sunset, March, 1924.

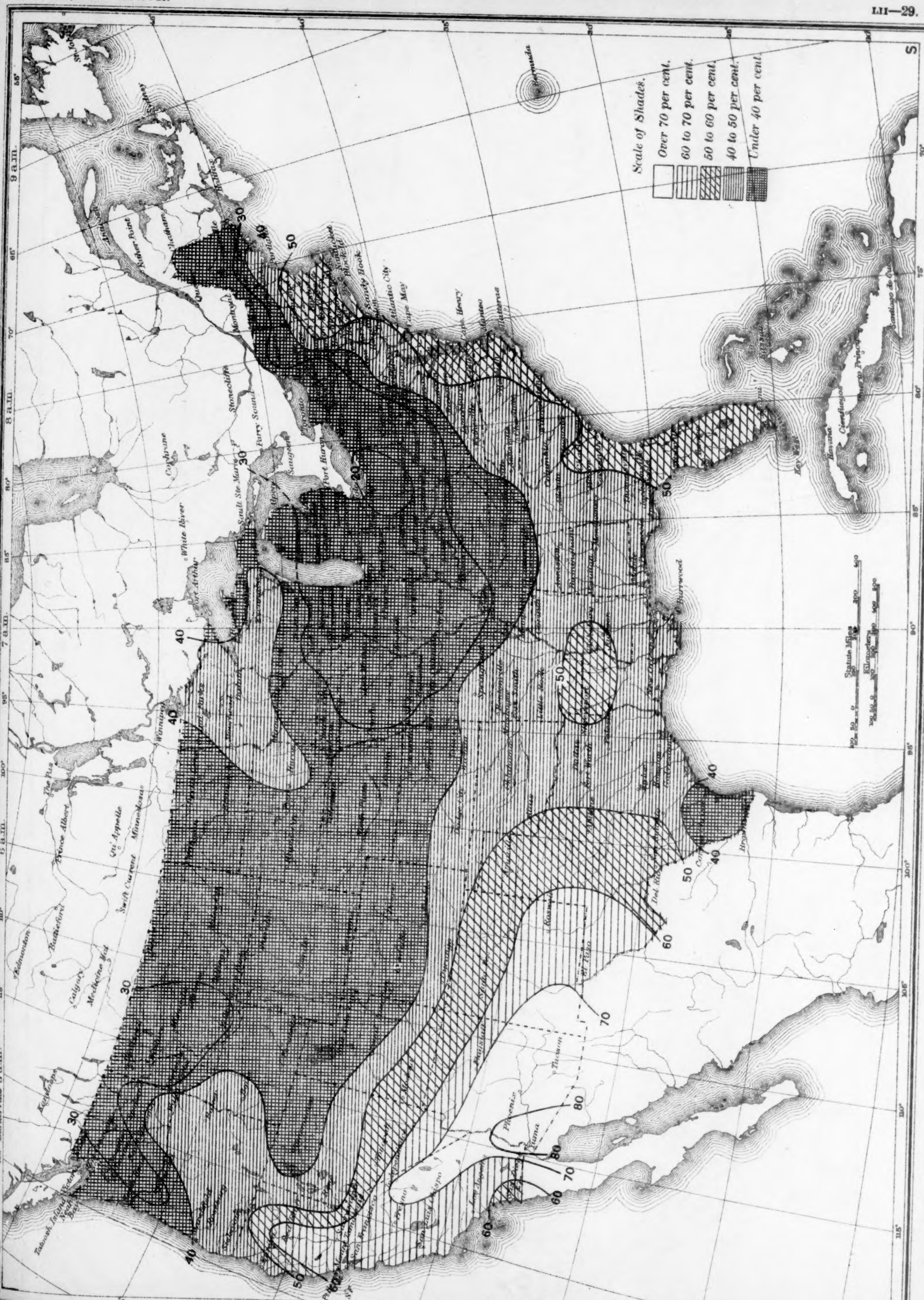


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, March, 1924.

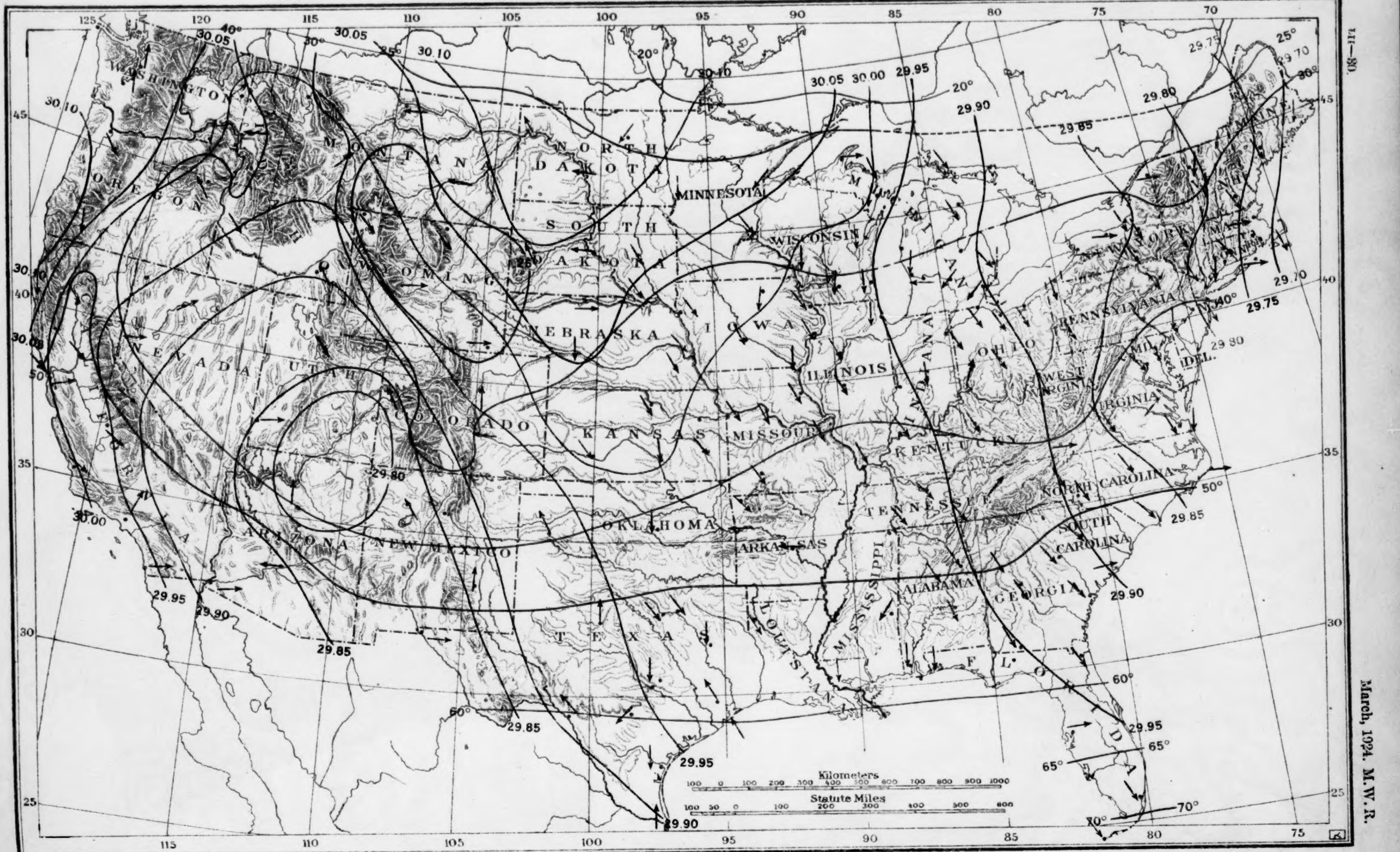
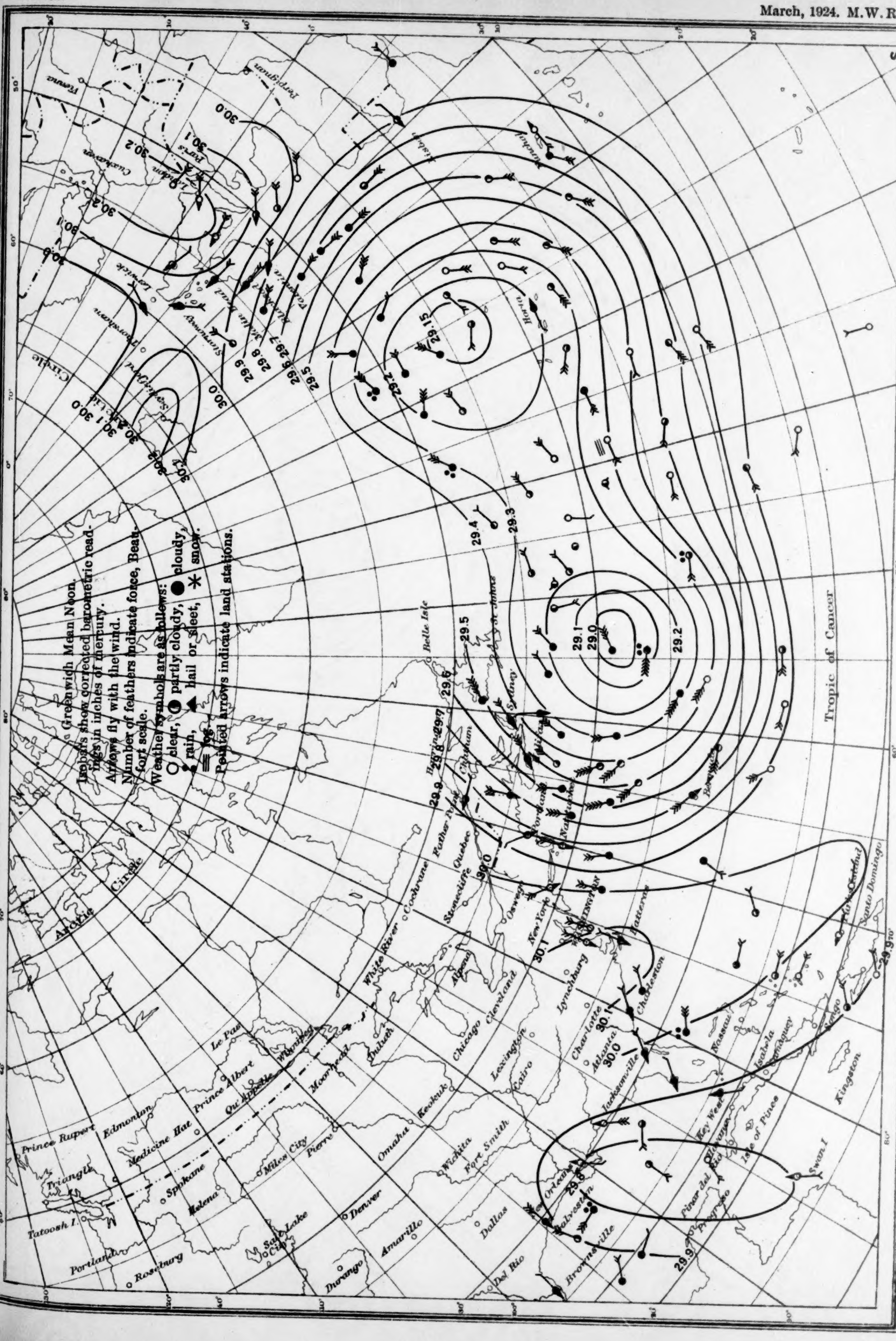


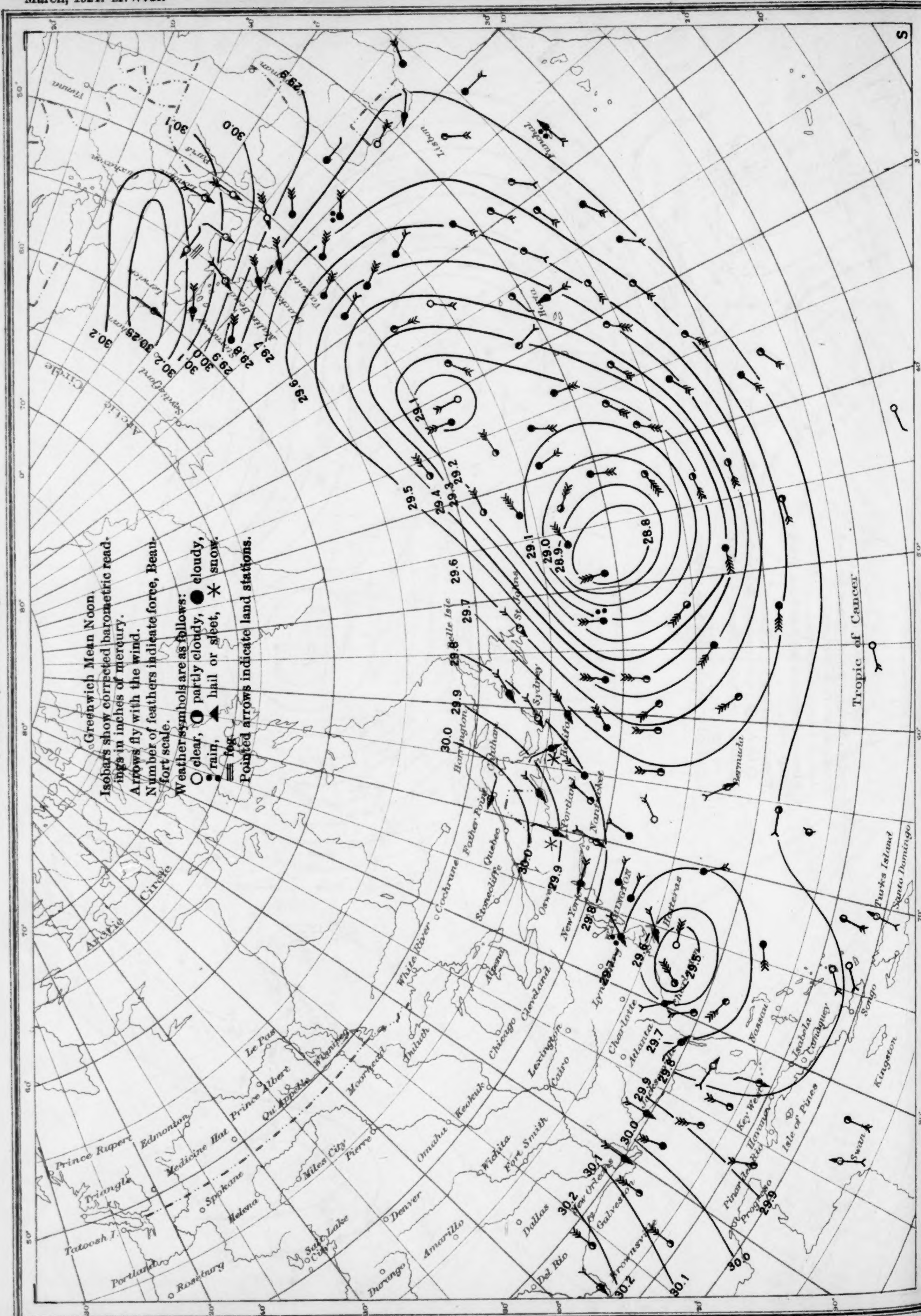
Chart VII. Total Snowfall, Inches, March, 1924. (Inset) Depth of Snow on Ground at end of Month.

Chart VII. Total Snowfall, Inches, March, 1924. (Inset) Depth of Snow on Ground at end of Month.



(Plotted by F. A. Young.)

Chart IX. Weather Map of North Atlantic Ocean, March 10, 1924.
(Plotted by F. A. Young.)



(Plotted by F. A. Young.)

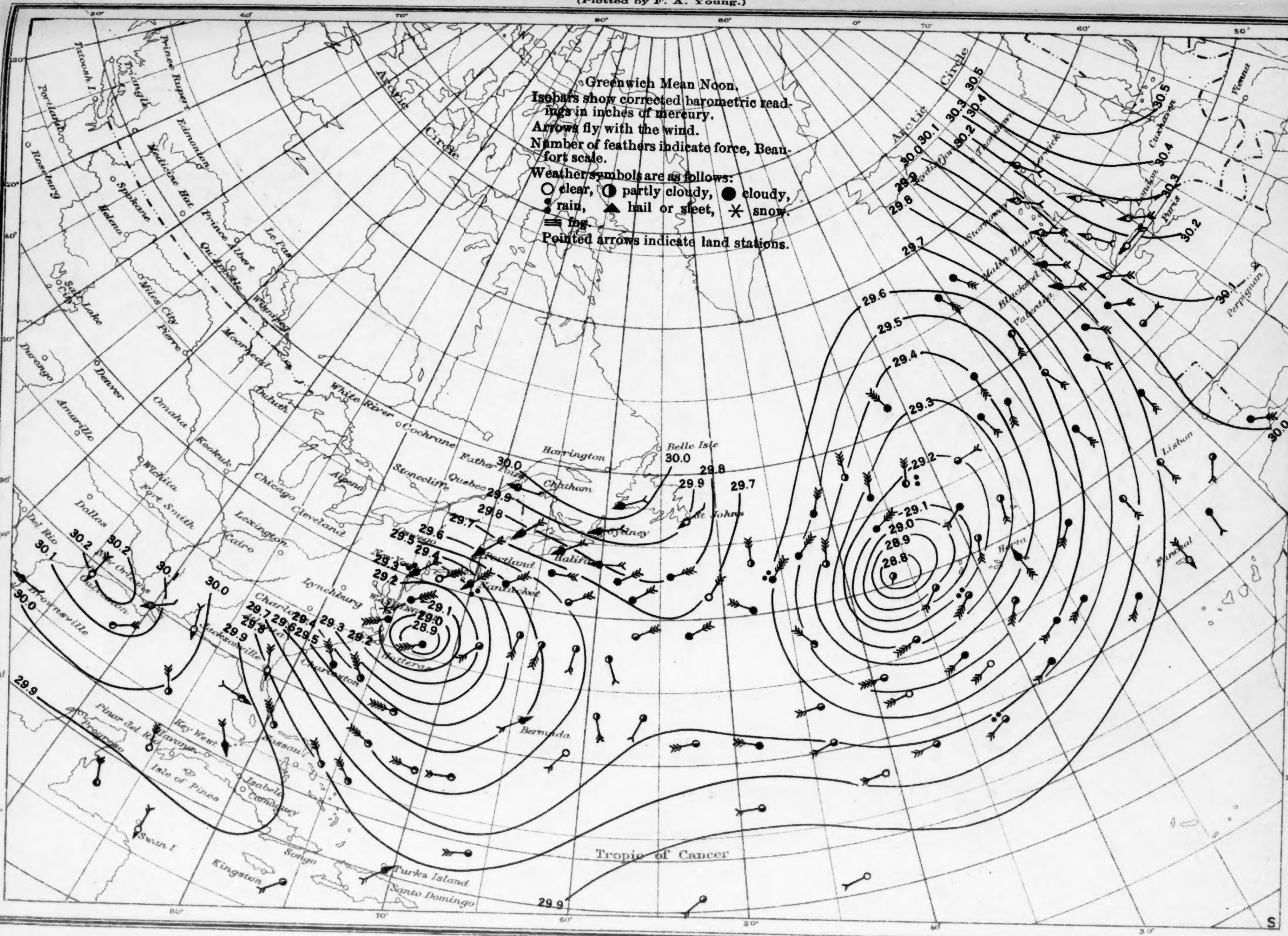


Chart XI. Weather Map of North Atlantic Ocean, March 12, 1924.

(Plotted by F. A. Young.)

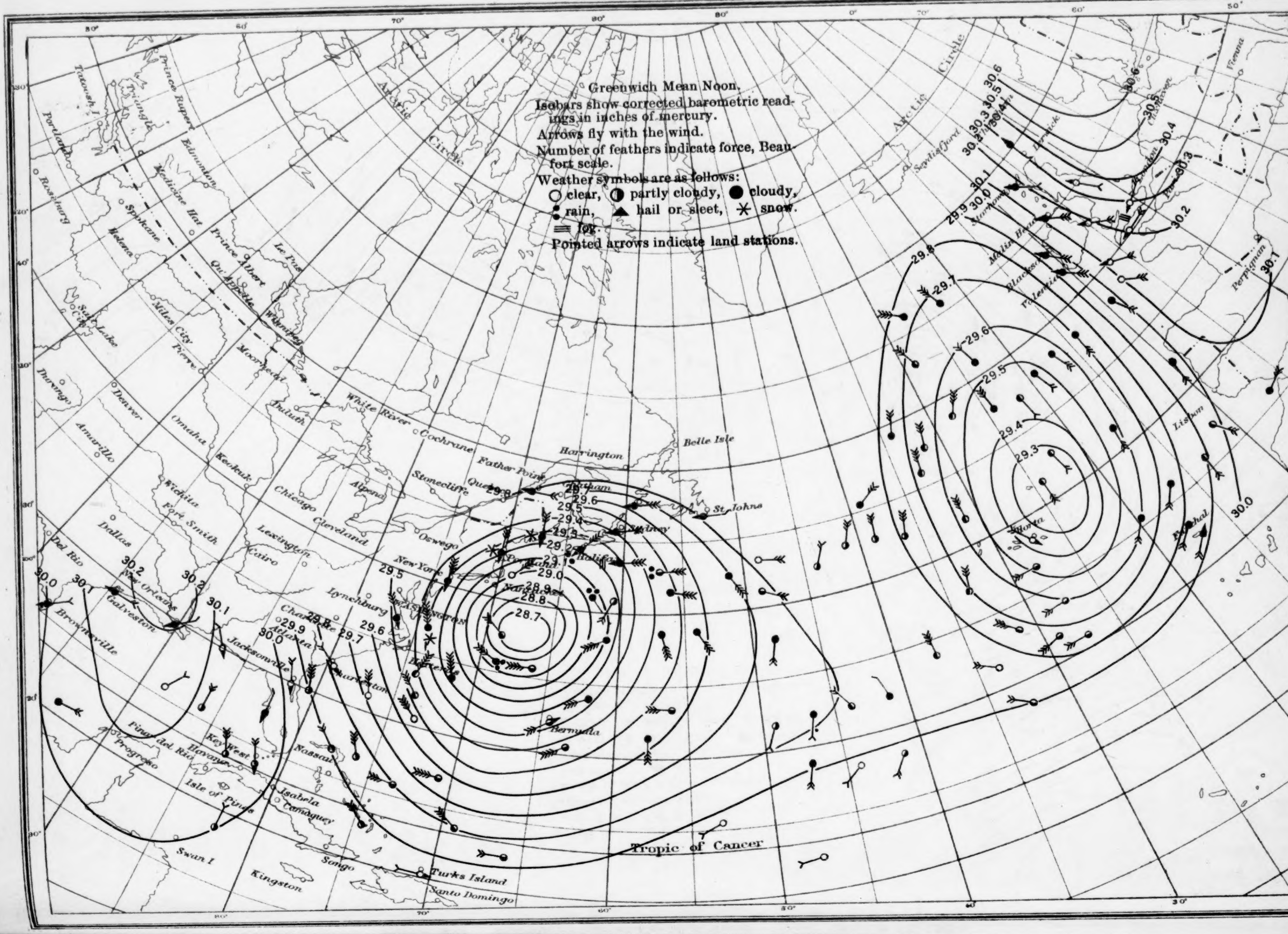


Chart XII. Weather Map of North Atlantic Ocean, March 13, 1924.

(Plotted by F. A. Young.)

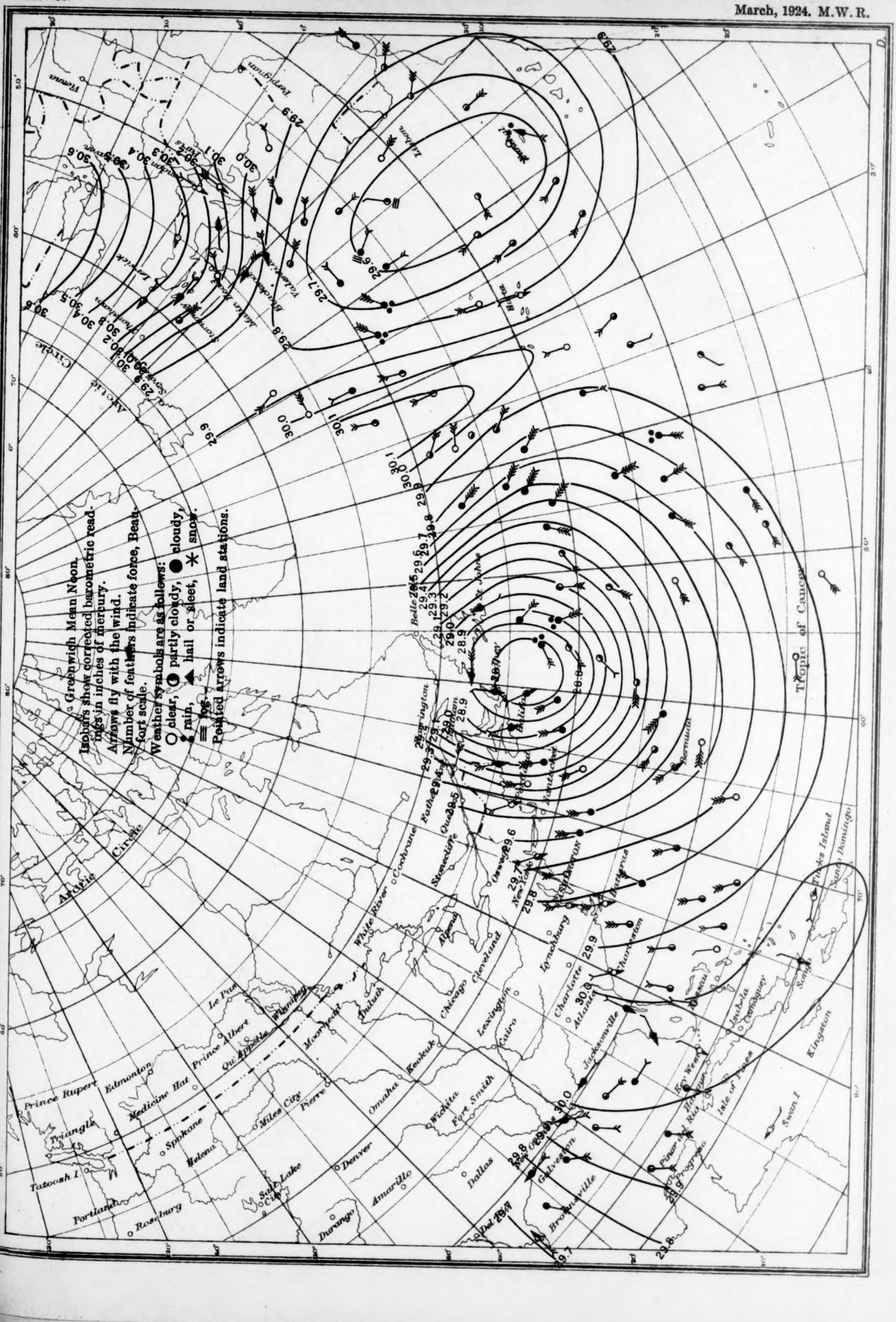


Chart XII. Weather Map of North Atlantic Ocean, March 13, 1924.
(Plotted by F. A. Young.)

Chart XIII. Weather Map of North Atlantic Ocean, March 14, 1924.

(Plotted by F. A. Young.)

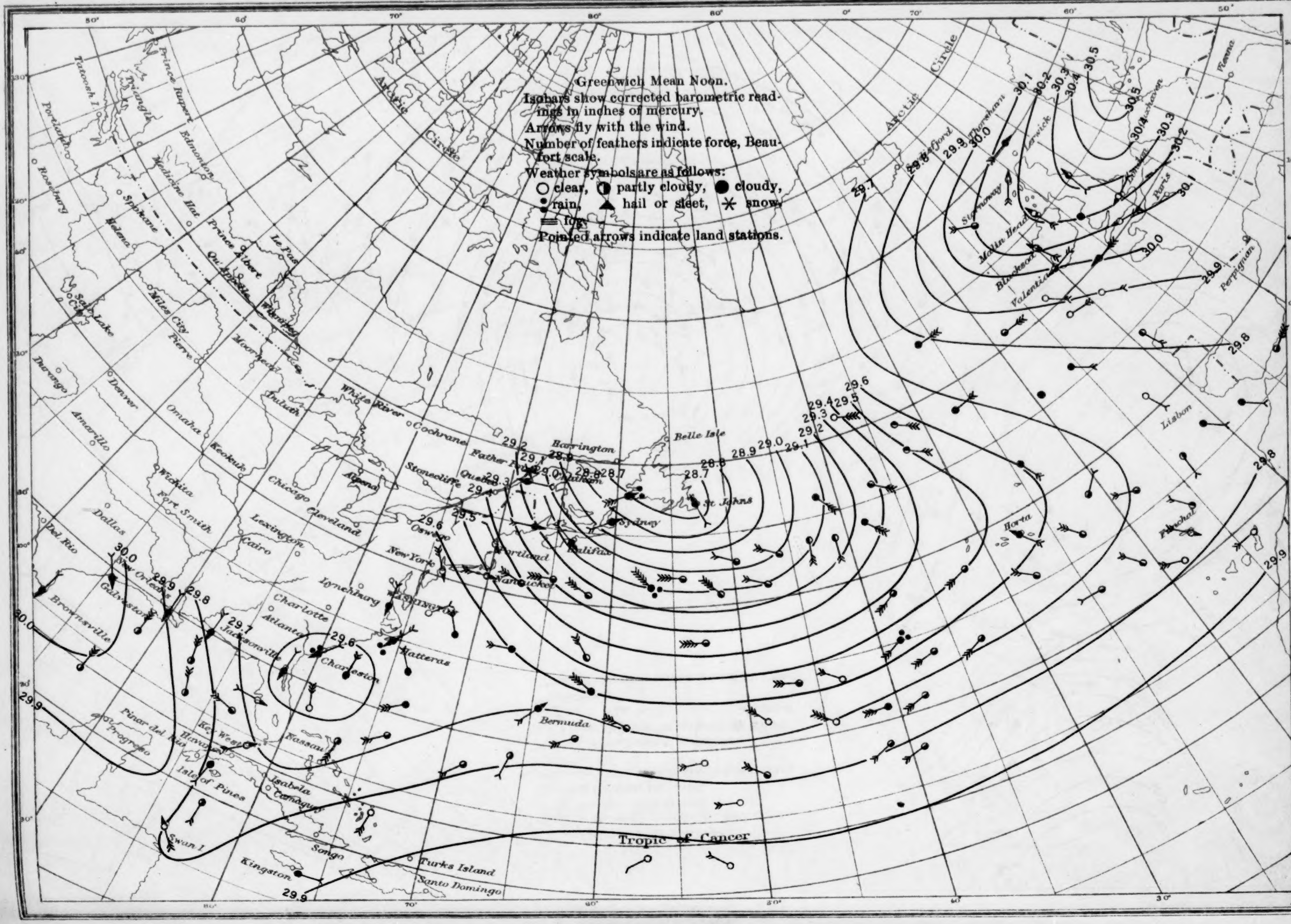


Chart XIV. Weather Map of North Atlantic Ocean, March 21, 1923.
(Plotted by F. A. Young.)

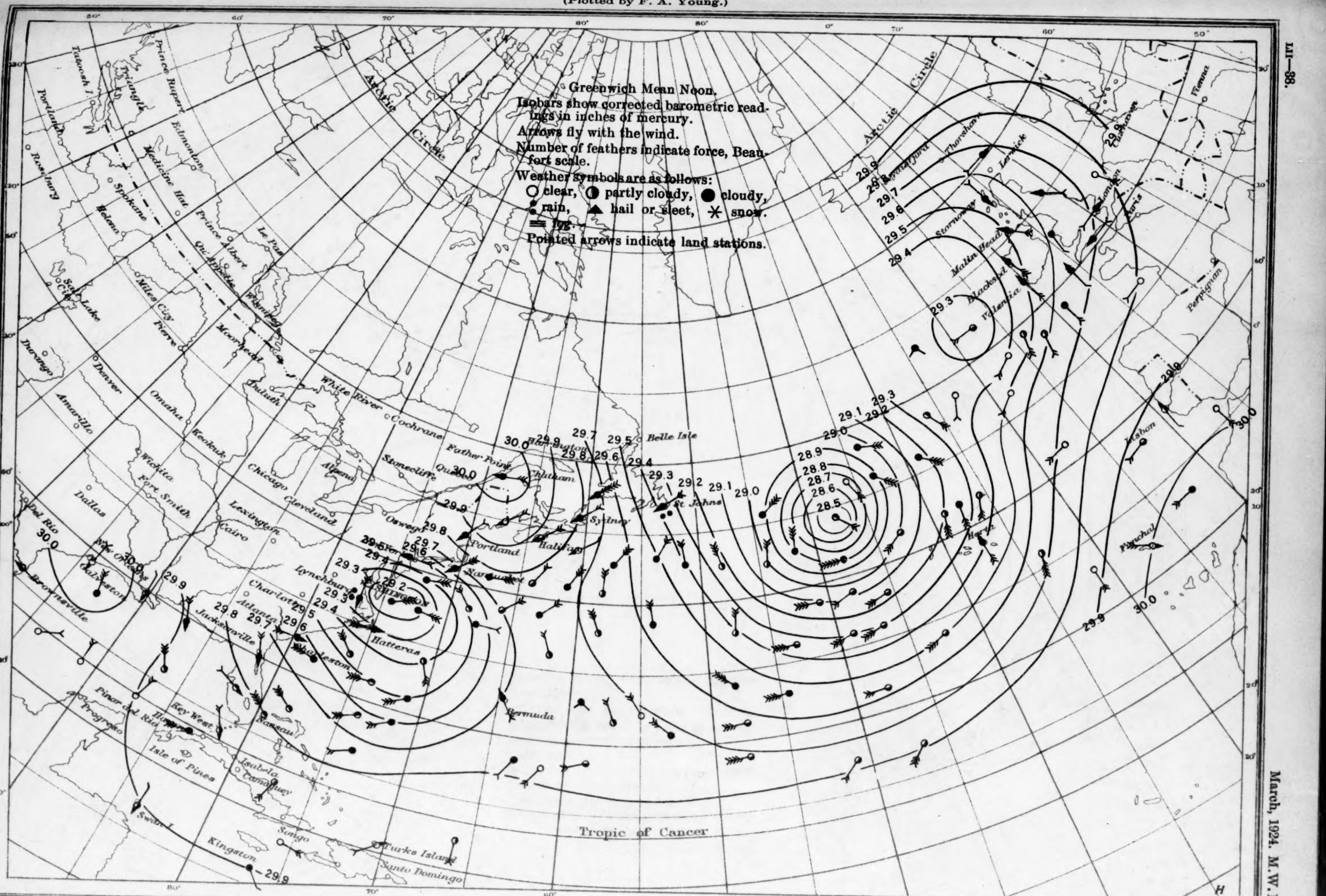


Chart XV. Weather Map of North Atlantic Ocean, March 22, 1923.

(Plotted by F. A. Young.)